EFFECTS OF SILICATES AND CARBONATES ON THE STATUS OF MINERAL NUTRIENTS IN A HYDROL HUMIC LATOSOL

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INTRODUCTION

Liming acid soils is an agricultural practice of long standing. Aside from replenishing calcium in calcium-deficient soils, lime also changes soil pH thereby influencing the availability of several mineral nutrients and depressing the solubility of elements which are potentially toxic.

Beneficial effects from silicates have been reported in the past. Some silicates are basic in reaction and calcium silicate supplies calcium. Slags containing calcium silicate have been used to release immobilized phosphate and improve the efficiency of phosphatic fertilizers in acid soils. Silicates applied alone or in conjunction with phosphate to some Hawaiian soils have improved the yields of sugar cane and Sudan grass. Why this is so has not been clearly established. It is possible that in highly weathered, low-silica soils silicate effects a yield response in ways other than its exchange with phosphate. In sugar cane this may be a silicon effect *per se* inasmuch as the response was not striking in soils having relatively high silicon content.

Since lime and slag materials are basic in reaction beneficial effects from their use, either direct or indirect, may be related to pH changes. Immobilization of aluminum and iron, increased solubility of sulfate and decreasing solubility of manganese to a non-toxic level are three possible benefits from raising the pH of latosols. Latosolic soils having high aluminum and iron oxides tie up sulfate in sparingly soluble form. Release of sulfur for plant use is effected in these soils through liming and application of silicates.

Accelerated weathering of soil minerals in the humid tropics is accompanied by an increase in aluminum and iron oxides in relation to silica. This condition leads to drastic changes in the availability of mineral nutrients. Phosphate especially has been found to be strongly fixed or immobilized by highly weathered, acidic soils. One solution to the problem is to apply large quantities of phosphatic fertilizers with the hope that competition from the soil will be sufficiently diminished and some phosphate will be available to the plants.

In Hawaii volcanic cinders high in silicon are abundant. These deposits could provide a cheap source of silicate materials if their decomposition is sufficiently rapid to provide an immediate and adequate supply of silicate and calcium for plant use.

The purpose of this study was to evaluate the effects of lime and siliceous slags and cinders on soil pH and mineral nutrient status in a Hydrol Humic Latosol.

LITERATURE REVIEW

Development of Soil Acidity

Weathering. The removal of bases by weathering is accompanied by hydrogen ion accumulation in the soil system. What remains mostly are aluminum and iron as shown by this weathering sequence of elements from soil minerals: Ca > Mg > Na > K > Si > Al > Fe.

Aluminum and soil acidity. The relationship between pH and active alumina was studied by Burgess (1923) who grouped acidic soils in Hawaii as (1) high acidity (pH 4.0 - 5.0) with active alumina of about 388 ppm. and (2) low acidity (pH 5.0 - 5.8) with active alumina of about 36 ppm. Later studies confirmed that aluminum solubility is high at low pH and decreases to almost nil at pH 7 (Magistad, 1925).

The concept that aluminum contributes to soil acidity was investigated by Chernov and Belyaeva (1946) using red loams (krasnozems), podzolic soils, humic acid, and kaolinite. They found aluminum more effective than hydrogen in replacing calcium in the foregoing materials. They then suggested that in acid soils calcium is replaced by aluminum.

Investigating the relationship between soil pH and extractable aluminum, Fox et al (1962) reported 4.76 me/100 g extractable aluminum (using N $BaCl_2$, pH 4.0) in a highly acidic Hydrol Humic Latosol (pH 3.8) and only 0.10 me/100 g in a slightly alkaline Dark Magnesium Clay (pH 7.8). In an Aluminous Ferruginous Latosol, Plucknett and Sherman (1963) reported a decrease in extractable aluminum (using N NH_4Ac-0.2N Ba Cl_2, pH 4.8) from 11.7 me/100 g at pH 5.1 to 5.7 me/100 g at pH 6.3. Lime was used to increase soil pH in this case.

Continuous application of nitrogenous fertilizers. Development of soil acidity through continued applications of inorganic fertilizers, especially ammonium sulfate, is frequently observed. Heavy applications of ammonium sulfate decreases exchangeable calcium and increases exchangeable potassium with the soil tending to become more acidic (Askew, 1934).

Variations in acidity and mobile aluminum of podzolic soils under the influence of mineral fertilizers were investigated by Koshel'kov (1939). He noted that nitrogenous fertilizers had the greatest influence on acidity and mobile aluminum. He then classified fertilizers into (1) NH_3 fertilizers which considerably increase acidity and mobile aluminum and (2) non-NH_3 fertilizers which are physiologically alkaline and decrease both acidity and mobile aluminum.

A retardation in development of soil acidity when commercial fertilizers, compost and lime were applied together was reported by Kobayashi (1940). Ammonium sulfate (applied 0.09% by weight to leaching columns) dissolved four times as much calcium as water from the soils studied. Loss in calcium through leaching by ammonium sulfate was greater in volcanic ash soils than in others of different parent materials (Dei and Maeda, 1958). The corrective effect of lime on acidity in latosolic soils of Puerto Rico was reported by Pearson et al (1962).

Correction of Soil Acidity

Liming. Liming is the age-old practice of correcting soil acidity. The effect of lime in the soil is four-fold as stated by Peck (1911): (1) provides calcium for plant nutrition, (2) replaces other minerals in their original combinations, changing them from insoluble to soluble forms, (3) improves soil structure, and (4) improves microbial activity.

The effect of lime as slag on soil reaction was reported by Voelcker (1873) as more permanent than that of quicklime. Increased yields of potatoes from an application of basic cinders was obtained by Kinch (1890). This response was attributed to phosphoric acid in the cinders and not to the lime content. However, the response could have been due to both.

Soils high in oxides and hydroxides of aluminum and iron have a high phosphate fixing capacity. This immobilized phosphate becomes more available when soils are limed because formation of insoluble iron and aluminum phosphates is retarded (Fried and Peech, 1946).

In Hawaii weathering of volcanic ash in high-rainfall areas gives rise to Hydrol Humic Latosols having low SiO_2/R_2O_3 ratio (Sherman, 1952) and high phosphate fixing capacity. The intensity of phosphate fixation in relation to the mineralogical systems of soils was studied by Fox et al (1962). Under Hawaiian conditions these investigators found the order to be: amorphous hydrated oxides > goethite-gibbsite > kaolin >2:1 clays. High phosphate fixing capacity of lateritic soils then is largely due to the abundance of iron and aluminum which immobilize the phosphate. Clay minerals also fix phosphate (Chu and Sherman, 1952). After removing amorphous oxides from a Low Humic Latosol, the clay fractions (kaolinite and halloysite) still fixed 30% of the added phosphate. The capacity of Hawaiian acidic soils to fix phosphate is so high that 98% to 99.98% of added phosphorus is immobilized (DeDatta, et al, 1963). Phosphate fertilization of latosols becomes costly because large amounts of phosphorus must be applied before phosphate becomes readily available to plants (Younge, 1961).

Conditions for formation of iron phosphates and their properties in relation to phosphate fixation in soils were studied by Scheffer and Schulz (1955). Oxidation of ferrous iron in the presence of phosphate and slow alkalinization in the medium results in products resistant to oxidation even though they may still contain small amounts of ferrous iron. Furthermore, when dissolution of ferrous hydroxide is promoted by complex-forming anions, reoxidation of iron by air or microbial activity in the soil islikely to lead to insoluble alkaline phosphates of ferric iron. A film of these insoluble phosphates may form around the fertilizer particles preventing further dissolution.

Phosphorus may accumulate largely as aluminum phosphate in acidic soils (Hutton et al, 1958). These workers showed a significant negative relationship between extractable aluminum and yield concluded that the depressing effect of aluminum on yield was counteracted by calcium phosphate. The amount of phosphate sorbed by soils was found by Coleman et al (1960) to be correlated with exchangeable aluminum. Removal of exchangeable aluminum by leaching with N KCl reduced phosphate sorption except in soils very high in oxides or hydroxides of iron and aluminum. Phosphate sorption by Al-clay was highest at pH 7 in salt-free systems. Coleman, et al stated further that phosphate fixation involving exchangeable aluminum seems to lead to formation of a substance possessing the composition of variscite.

Lime and Its Effect on Cation Exchange Capacity

Increased cation exchange capacity of soils limed with calcium hydroxide and carbonate was reported by Davis (1945). The increase was separate from, and independent of, the increased adsorption of polyvalent cations by the soils as a result of formation of basic salts with weak colloidal acids. In Hawaiian Hydrol Humic Latosols, Rixon and Sherman (1963) failed to obtain a significant increase in cation exchange capacity by liming.

Liming to Modify pH and Provide Calcium

Soil acidity is often injurious to plant growth, although usually indirectly. Extensive investigations have been conducted on this subject over the years. Arnon, et al (1942) stated that injury to roots from the acid reaction of the medium was apparent only at pH 3. Three indicator plants were observed in this study: tomato, lettuce and Bermuda grass. All three plants failed to adsorb calcium and phosphorus at pH 3. Furthermore, tomato and lettuce also failed to absorb other ions at this reaction. In alkaline solutions (pH 9) phosphorus absorption by the indicator plants was greatly diminished. There was lower calcium absorption, particularly by tomato and lettuce, from strongly acid solutions (pH 4 and 5) than at higher pH values. No profound effects on the absorption of magnesium, potassium and nitrate were noted between pH 4 and 9.

Potentially toxic elements, notably aluminum, manganese and iron, are precipitated from soil solutions with increasing pH. Some of these are essential nutrients for plants. Therefore, correcting acidity may not always increase crop yields (Kirsanov, 1940). Iron, along with manganese, was found to be deficient in alkaline soils. Manganese and iron may then have to be sprayed on crops requiring high amounts of these nutrients when they are grown on acidic soils that are limed heavily. Phosphorus content of plants decreased with increasing calcium carbonate applied and increased with increasing phosphate if the carbonate was not sufficient to decrease solubility of phosphate (Loo et al, 1956).

Some soils, especially krasnozems, do not release phosphorus even if limed unless their pH exceeds a certain critical limit (5.5 for krasnozems as reported by Loo et al, 1956). Above this pH, phosphorus absorption by roots increased. Favorable effects of liming above this reaction were attributed to decreased phosphate absorption by the soil and increasing absorption by roots of phosphorus which was otherwise sparingly soluble. Recent work (Fox et al, 1964, in press) has demonstrated that for phosphorus uptake by plants optimum pH of Hawaiian latosols is between 5 and 6.

The residual effect of lime on pH in the profile of lateritic soils was investigated by Brown and Munsell (1936) and Pearson et al (1962). They concluded that applying lime by mixing with the plow layer or by broadcast on the surface had similar effects. They explained the reduction in subsoil acidity of the limed plots as due to continuing disintegration of limestone and not to mass movement of exchangeable bases to lower depths at the expense of the upper. Degree of reduction in acidity and the depth of the effect were determined by the amount of limestone applied and time.

Liming experiments in Hawaii have given variable results. Yields of the sugar cane variety Yellow Caledonia were depressed by "heavy" (750 - 1000 lb/A) applications of basic slag on neutral to slightly alkaline soils (Larsen and Pratt, 1917). Varieties grown on Hydrol Humic Latosols evidently differ in their calcium requirements (Verret, 1918). The variety Lahaina responded to both lime and gypsum whereas variety D-1135 did not. Much more recent studies by Clements (1962) showed response by variety 49-5 to coral stone applications on a Hydrol Humic Latosol. Uichanco (1959) reported sugar cane yields from rates of liming up to 4.5 T/Ha. The first increment (1.5 T/Ha) of lime was associated with an unexplained decrease in yield.

Liming Hawaiian sugar cane soils has been extensively studied by Ayres (1961). The results seemed to indicate that benefits associated with liming are due to provision of calcium in acidic soils and not to pH effect per se.

Hydrol Humic Latosols are not only highly acidic but also have high buffering capacity (Matsusaka and Sherman, 1950). Large amounts of lime are required to neutralize the acidity of these soils. Rixon and Sherman (1962), found that 46,000 lb/A of crushed coral stone were required to increase the pH to neutral.

Liming and Interactions of Other Nutrients

Danger from overliming has been emphasized by many workers (Greene, 1954; Pearson et al, 1962; and Fox and Plucknett, 1964). Aside from the possibility of immobilizing micronutrients, phosphorus availability may also be decreased when lime ties phosphate up as calcium phosphate of low solubility. This problem is probably not so serious as phosphate fixation by acid soils since, in an acid environment, calcium phosphate is more soluble than iron or aluminum phosphate.

Continued use of lime has brought attention to interactions among nutrients in the soil and nutritional balance in plants. The effects on several plants of varying the ratio between lime and magnesia added to soils were studied by Bernardini and Corso (1907). Their conclusions substantiated Japanese research that the Ca/Mg ratio for normal development of wheat, rye, oats, rice and barley is 1:1; for maize, onions, spinach, flax and cabbage, 1:2; and for legumes, 1:3.

Liming also disturbs the Fe/Mn ratio in plants which could drastically affect yields. Johnson (1924) showed that manganese chlorosis of pineapple in Hawaii was corrected with iron sulfate spray and the average weight of fruits was higher in the sprayed than in the unsprayed area. For normal development of soybeans, a ratio of 1.5 to 2.5 for Fe/Mn is necessary (Somers and Shive, 1942, cited by Stiles, 1961).

Greene (1954) has called attention to the problem of micronutrient deficiencies caused by overliming in the tropics. This is in keeping with the classical diagram of Truog (1946) which gives the influence of soil reaction on nutrient availability. Except for molybdenum, the micronutrients become less available as soil pH increases beyond neutral.

Basic slag phosphate was compared with tricalcium phosphate by Behrens (1935). In the absence of calcium carbonate he found that slag phosphate was better utilized than tricalcium phosphate. He attributed this to increased calcium concentration rather than to pH.

Experiments with sugar cane showed that application of calcium increased the calcium content of cane tissues without impeding the assimilation of R_2O_3 from soils derived from the metamorphic rocks diorites, serpentines, schists, and sandstones (Bonazzi, 1936).

The effect of Ca/K ratio on the absorption of phosphate and other nutrients was studied by Abareda et al (1958) who found that phosphate uptake by wheat was most pronounced when the Ca/K ratio was 2. They did not elaborate why at this ratio there was considerable phosphate absorption. It may have been due to increased phosphate uptake as a result of improved growth. They also stated that less magnesium and sodium were absorbed as the Ca/K ratio increased. Although they did not offer any explanation for this, it may have been due to ionic antagonism. Calcium, as expected, was antagonistic to potassium and sodium at high concentrations. But why calcium depressed magnesium at high concentrations was not explained.

Aluminum toxicity may be associated mainly with its effect on the K/Ca of plants while manganese affects both the Fe/Mn and K/Ca ratios (Rees and Sidrak, 1961). Increase in concentration of either iron or manganese in relation to the other depressed accumulation of other metals in both leaves ant the whole plant of dwarf kidney bean. Increase in calcium concentration decreased absorption of both metals. Calcium level was found to be the determining factor for the optimum Fe/Mn ratio for healthy plants.

Increase in aluminum concentration (0 - 16 ppm) was found not to affect boron contents in the tissues but calcium concentration in the roots (but not in the tops) decreased with decreasing aluminum accumulation in the roots (Hortenstine and Fiskell, 1961). The possibility of releasing phosphorus from insoluble iron and aluminum phosphate by exchange of sulfate from gypsum thus resulting in the more soluble calcium phosphate, was suggested by Peck (1911).

Liming and Mineralization of Organic Matter

That liming enhances ammonification by soil microbes was shown by Kopeloff (1916) who noted that maximum ammonification by *Rhizopus nigricans*, *Zygorrhyncus vuilleminii* and *Penicillium sp. 10* was at pH between neutral and acidity equivalent to 2000 pounds calcium oxide per acre. This held true in both sandy and clay soils. He observed further that in general, acidity equivalent to more than 2000 pounds calcium oxide per acre and pH above neutral depressed ammonification in the soils studied. Blair and McLean (1916) also studied the influence of lime on yield and nitrogen content of corn. They attributed increased growth and nitrogen content to increased organic mineralization in the limed as a response to liming. This conclusion was also reached by Ghani and Saleem (1942) and McIntire, et al (1947) but they also attributed some effect to mineralization of organic phosphorus which accompanied liming.

Both nitrogen content and dry weight of legume on unlimed plots were found significantly lower than those with lime (Klingebiel and Brown, 1938). In the limed plots nitrogen content and dry weight were significantly higher in the inoculated than in the uninoculated plants. This supports the results of earlier studies about the beneficial effect of lime on microbial activity, especially of nitrogen-fixing organisms.

Effect of Liming on Potentially Toxic Elements in the Soil

Lime may act upon injurious compounds in soils by neutralizing acidity thus precipitating certain injurious substances and to a certain extent by reducing the ill effects of ions even when they are not precipitated. Conner (1921) attributed much of the harmful acidity of soils to the presence of soluble aluminum salts. This was confirmed by Magistad (1925). The possibility of aluminum toxicity on nitrifying bacteria was emphasized by Denison (1922) who stated that aluminum salts stimulated ammonifying organisms but adversely affected nitrifying bacteria in the soil. He found calcium carbonate to be the most effective material in reducing the toxicity of aluminum.

Rixon and Sherman (1963) found a significant negative correlation between extractable aluminum and exchangeable calcium and the degree of this correlation increased with increasing rates of lime.

Silicate Studies

Silicates as soil amendments for many years. As early as 1873 Voelcker recommended iron slag for the improvement of vegetation on moorlands and peaty soils. The effect of silica on the improvement of soil physical conditions may improve soil aeration and microbial growth and lead to better phosphate availability (Laws, 1950). After investigating the effects of artificial silication on volcanic ash soils Onikura (1959) showed that cation exchange capacity increased in proportion to the rate of silication. Cation exchange capacity increased in the surface soil independently of the amount and quality of humus and was mainly due to formation of stable amorphous aluminum silicate. He found also that in an alkaline medium the increase in cation exchange capacity was affected by polymerization of silica. Comparing the effects of blast-furnace slag and "falling" hematite slag, Cooke (1956) noted that blast-furnace slag behaved like calcium carbonate in the soil. Suehisa, et al (1963) found that soluble silicates increased pH of latosols whereas colloidal silica produced the opposite effect. They attributed the liming effect of sodium metasilicate to the hydrolysis of the material into sodium hydroxide and silicic acid. Increasing rates of calcium silicate increased pH in both Hydrol Humic and Humic Ferruginous Latosols (Monteith and Sherman, 1963). The increase, however, was not so great as that from calcium carbonate.

Effect of silicates on phosphate availability. The role of silica in phosphorus utilization in plants was studied by Jodin (1883), cited by Clements (1965). These workers attributed the beneficial effects of silicon upon phosphate utilization as a function occurring in the plant and not in the soil.

The influence of calcium silicate on phosphorus availability and crop response was reported at the beginning of the 20th century by Hall and Morison (1906). Their observations were substantiated later by Schollenberger (1922 and 1947). The silicate anion may exchange with the phosphate anion fixed in the soil, making the latter more available to plants (Batisse, 1946 and 1950 and Dean and Rubins, 1947). Anion exchange is pH-dependent and silicate displacement of phosphate was found practically nil at pH 4 when no calcium or magnesium was added in conjunction with silicate (Reifenberg and Buckwold, 1954). These workers found that phosphate displacement by silicate was most effective at or slightly below neutral reaction.

A decreasing trend in phosphorus content of maize with increasing rates of silicon applied was reported by Batisse (1950). However, there was a response in growth to silicon application. He attributed this response to probable retardation of phosphate fixation by silicate although the possibility of influence of silicon on the growth response could not entirely be ruled out. Williams and Vlamis (1957) suggested that silicon, though not listed as an essential element, may have secondary effects on improvement of plant growth. They reported that silicon reduced manganese necrosis in barley by preventing localization of manganese in small spots in the leaves. Clements (1965) reported that part of the response of sugar cane to TVA slag treatments was due to decreased manganese uptake thereby reducing incidence of "freckling" disease. This suggests that silicon may improve distribution of some nutrients in plants or conteract adverse effects of some nutrients within the plant.

Increased phosphorus content in soybeans fertilized with sodium and magnesium silicate was reported by Dewan and Hunter (1949). This increase disappeared after eight weeks. An inverse relationship between phosphorus response and water-soluble and citric-acid-extractable silicon was obtained by Birch (1953). Silicates enchanced phosphorus utilization at low levels at phosphorus but not at higher concentrations (Raleigh, 1953). Phosphorus leached more readily in the silicated plots, indicating that phosphotus became more soluble. Comparing the effects of silica and silicate, Noda (1952) found that silica had a greater effect in preventing phosphorus fixation. Yield and phosphorus uptake increased when 1000 ppm disilicate (Si_2O_5) was applied to oats (Albritton, 1957).

Grohse-Brauckmann (1956) stated that phosphorus fertilization increased silicon uptake by cereals, indicating anion exchange.

The possibility of "antagonism" between silicon and phosphorus was suggested by Engel (1958) who showed decreased silica uptake by wheat when applied silica was applied to culture solutions in the presence of phosphate. He stated further that silica accumulated in insoluble form in the plant and remained in the tissues even after transferring the plant to silicate-free solution. Silicon deposited in the roots and stalks remained in the tissues even after the supply was stopped. Evidently, silicon is highly immobile in wheat. This is somewhat in conflict with the concept of improved distribution of nutrients in sugar cane as influenced by silicon.

Polynov (1937) stated: "It now appears that silica is an important factor in the utilization of phosphoric acid by plants . . . and its exclusion from the group of organogens is not altogether correct."

Silicates and other nutrients. Silica in the ash of wheat straw was inversely related to the yielding capacity of the soil (Nayar, 1957), denoting that plants absorb much silicon even if other nutrients are deficient. Higher contents of sugar, starch and protein were found by Okamoto (1959) in rice treated with silicic acid. This treatment was associated with greater translocation of these materials into the panicles; a yield response and, under adequate moisture supply, hastened heading and maturity. Rice growth was poor and manganese was high when silicon was deficient (Yoshida, et al 1959). Plants were susceptible to diseases and excessive transpiration. This finding seems to be in accord with observations by Clements (1965) that a decrease in manganese uptake by sugar cane accompanied TVA slag applications and corrections of "freckling" disease. Silicon absorption by rice increased proportionally with increased absorption of nitrogen, phosphorus, potassium and manganese (Takijima, et al 1959). They also noted a higher content of ammonium nitrogen in the plants receiving slag and silica gel. Rhoads, et al (1956) found a decrease in manganese uptake by avocado seedlings with silicate application. However, they attributed this decrease to increased soil pH and not to silicon uptake. Grohse-Brauckmann (1953) showed that uptake of silica by cereals was decreased by lime, indicating probable immobilization of silica by lime in the soil. Clements (1965) reported the following results from a series of seven TVA experiments on sugar cane on the island of Hawaii: significant reduction in magnesium uptake, 4 experiments; decreased manganese uptake, 6; 4 were significantly lower in boron uptake; significant reduction in both copper and zinc uptake in only 1; no significant decrease in molybdenum uptake in all; and 6 significantly increased in calcium uptake. The TVA slag used in these experiments contained almost 50% calcium oxide equivalent.

<u>Silica and disease resistance by plants.</u> Takijima, et al (1949) reported that rice receiving silica showed resistance to sesame spot disease and rice blast. This probably indicates that silicon makes the cell walls tougher to penetration by both fungus and insects.

MATERIALS AND METHODS

Nature of Study

The Hydrol Humic Latosols of Hawaii have posed many nutritional problems. Therefore, soil samples from three field experiments were investigated in a study of effects of silicate and carbonate on the availability of mineral nutrients in this soil group.

One of the three experiments was a comparison of the effects of TVA slag, volcanic cinders and a mixture of volcanic cinders and coral stone. Throughout the remaining discussion this will be referred to as the "silicate experiment." In this trial the determining factors in the rates applied were the silicon and calcium contents of the TVA slag. The other two field trials were lime and phosphate experiments. The first, hereafter called the "low-lime" experiment, was established seven years prior to sampling. It was used to determine the residual effects of lime on soil pH and calcium. The second, henceforth termed the "lime-phosphate experiment," was used to observe the effects of lime on the plant utilization of applied phosphorus and other elements and also to study the residual effects of high rates of liming on profile pH and exchangeable cations.

All three field experiments were located on the Pepeekeo Sugar Plantation (C. Brewer and Company of Hawaii) on the Hilo coast, Hawaii. These experiments were designed and installed by C. Brewer Company and plantation personnel while soil sampling and analyses were done by University of Hawaii personnel assisted by the Plantation.[1]

Description and Location of Soil

The experimental soil, a Hydrol Humic Latosol, was classified by Cline and his associates (1955) as follows:

Order:	Zonal
Suborder:	Latosol
Great Soil Group:	Hydrol Humic Latosol
Family:	Akaka
Series:	Akaka
Type:	Silty clay
Phase:	Undifferentiated

The Akaka series is a yellowish-brown Hydrol Humic Latosol (called Hydrandept in the 7th Approximation of Soil Classification) derived from volcanic ash at altitudes of 800-6000 feet on the windward sides of Hawaii and Maui islands. Annual rainfall ranges from 120-300 inches. Among the Hydrol Humic Latosols, the Akaka series is the most highly leached and most acid. Water content ranges from 150% to 400%. These soils are gels which exhibit thixotropy and

[1]The author wishes to thank Messrs. Herbert Gomez and Myron Isherwood, Jr., Plantation Manager and Crop Control Superintendent, respectively, for their permission and assistance to sample the experiment.

irreversible dehydration (Kanehiro and Sherman, 1956). The prevailing slope where the samples were taken is 5% to 10%. Ayres (1943) gave this analysis (field-moist basis) of the Akaka series: cation exchange capacity, about 37 me/100 g; base saturation, 4% to 5%; and organic matter, 15% to 20%.

The modal profile of the Akaka series is described by Cline and Associates (1955) thus:

A_0 2-5 inches of brown partly decomposed vegetative debris which is soft, wet, and mushy; extremely acid in most places.

A_1 0-7 inches, dark-gray to dark grayish-brown silty clay loam; hard when dry, friable when moist, and strongly smeary when wet; pH, 4.0 - 5.0; roots, very numerous.

B 7-30 inches, yellowish-brown silty clay loam; weak, medium crumb structure, very hard when dry, friable when moist, and strongly smeary when wet; pH, 4.0 - 5.5; roots, numerous in the upper part and decrease with depth; commonly faintly mottled with gray in the lower part.

C 30 inches +, mottled yellowish-brown, gray, and rusty brown highly weathered volcanic ash; silty clay loam, similar to B in consistence; rests on lava bedrock (D), generally below 5 feet.

Experimental Design and Treatment Materials

Two field layouts were used: a randomized complete block for the silicate and low-lime plots and a factorial for the lime-phosphate trial. The silicate and lime-phosphate experiments were replicated 4 times while the low-lime trial was replicated 5 times.

Plot size varied slightly among experiments but all were almost 0.05 acre each. Eight rows of sugar cane were grown on each plot spaced 4.5 feet between rows and each row was 44 feet long. Varieties of sugar cane planted were 49-5 in the silicate and low-lime experiments and 44-3098 in the lime-phosphate experiment. Plantation applications of nitrogen, phosphorus and potassium were made on all plots at one- to two-month intervals for N and K up to 12 months and once for P just before planting.

All treatment materials were rototilled into the soil immediately before planting.

Silicate experiment. Field plots for the silicate experiment were located in a portion of Field 104 near Akaka Falls, Hawaii, elevation 1250 feet. Slope is about 5% to 10%. Mean annual rainfall over this area is 183 inches (Rixon and Sherman, 1963).

Two silicate-bearing materials were used in this study: TVA slag and volcanic cinders of geologically recent origin found in abundance at Kau, Hawaii. The crushed cinders were a mixture of various sizes all of which would pass through a 16-mesh sieve. The chemical compositions of these materials are shown in Table I.

TABLE I. CHEMICAL COMPOSITIONS OF MATERIALS USED IN THE SILICATE TRIAL[1]

Elemental oxide	TVA slag	Volcanic cinders
	%	%
P_2O_5	1.0	0.057
CaO	49.8	2.72
SiO_2	39.8	65.78
Al_2O_3	5.7	1.60
Fe_2O_3	0.6	7.10 (FeO)
MgO	0.4	6.56

[1]Slag analysis came from TVA and that of cinders, after Clements, 1965.

Three treatment series were established: TVA slag, volcanic cinders and a mixture of volcanic cinders and coral stone. Silicon contents were equal in each level for all carriers of silicate and calcium level in the TVA slag series was equalized with coral stone in the mixture of volcanic cinders and coral stone. The chemical analysis of the coral stone used in this experiment is in Table II. Five rates (shown in Table III) were used in each series and the materials were applied on April 3, 1963. Soil samples were taken on November 27, 1963 when the cane was about seven months old.

Low-lime Experiment

The low-lime experiment was established in Field 103 near Akaka Falls on July 13, 1956. This field is near the silicate experiment so that the mean annual rainfall, slope and soil in these two areas are about the same. Elevation of the plots is 1150 feet. Crushed coral stone, having the analysis in Table II, were applied at five levels: 0, 0.5, 1.0, 2.5 and 5.0 T/A. Soil samples were taken on the same date as in the silicate plots.

Lime-Phosphate Experiment

The lime-phosphate experimental plots were laid out in Field 290 with slope and annual rainfall approximately the same as in the silicate experiment. It is 900 feet above sea level. This trial was a 3 x 4 factorial. Crushed coral stone was applied at 0, 2, 9.5 and 17 T/A and phosphorus, as under-acidulated rock phosphate, at 0, 88 and 176 lb/A P. The materials were applied on June 6, 1959 and the plots sampled on June 24, 1964.

TABLE II. CHEMICAL ANALYSIS OF CORAL STONE USED AS LIMING MATERIAL[1]

Elemental oxide	Percentage
$CaCO_3$	92.4
SiO_2	0.5 - 3.0
Fe_2O_3	0.25 - 0.55
MgO	0.4 - 0.7
Al_2O_3	0.6 - 1.09
Na_2O	0.05
K_2O	0.02
P_2O_5	0.035
SO_2	0.01

[1]After Clements, 1962.

TABLE III. RATES AND Si CONTENTS OF SILICATE CARRIERS USED

Level	Volcanic cinders		Volcanic cinders		Volcanic cinders + coral stone	
	Rate	Si	Rate	Si	Rate	Si
	Tons/A					
1	0	0	0	0	0	0
2	2	0.35	1.22	0.35	2.65	0.35
3	4	0.70	2.44	0.70	5.30	0.70
4	6	1.05	3.66	1.05	7.95	1.05
5	8	1.40	4.88	1.40	10.60	1.40

Soil Sampling

Surface-soil samples were taken at 5 locations in a diagonal direction across each plot, using a spade and digging about 6 inches deep. Profile samples were obtained with a 3-inch soil auger in 6-inch increments down to 4-foot depth. Three borings were made in a diagonal direction on each plot. Profile samples were taken from three of the five replications of the low-lime plots and from all lime levels of the zero-phosphate series in the lime-phosphate experiment.

Soil samples were thoroughly mixed and about 5-pound composites for the surface-soil and 2-pound composites of each depth increment of the profile were sealed in double polyethylene bags. This was done to prevent irreversible dehydration of the soil (Kanehiro and Sherman, 1956).

Greenhouse Experiment

This test was conducted to investigate the effects of field applications of lime and silicate on growth and mineral composition of two different plants: Sudan grass, *Sorghum vulgare* var. *sudanense* and Para grass, *Panicum purpurascens*.

Surface-soil samples from all replications of the silicate and lime-phosphate plots were composited. Then 1300 g moist soil containing $40 \pm 3\%$ dry matter in the silicate plots and $45 \pm 3\%$ dry matter in the lime-phosphate plots (about 0.5 kg soil on oven-dry basis) were weighed into 46 oz. cans lined with polyethylene bags. The soil in each can was poured onto a polyethylene sheet, spread evenly and thinly, and a solution of monocalcium phosphate containing P^{32} was pipetted and spread evenly as possible on the soil. The soil was then thoroughly mixed. Final concentration of added phosphorus in the pots was 100 ppm on moist soil basis. Blanket application rates of other nutrients (shown in Table IV) were made.

The planted pots were arranged in a completely randomized fashion in the greenhouse and a re-randomized occasionally to minimize variability from light and other sources.

Silicate Experiment

About 25 Sudan grass seeds were sown per pot about 1/4 inch deep on July 25, 1964. Pots were covered with paper till germination. Distilled water was weighed into pots regularly to maintain adequate moisture at field capacity.

On July 30 the plants were thinned to 19 seedlings per pot and on August 2, to 15 plants per pot. A dilute malathion spray was used to control insects. Harvest was on September 5 (about 6 weeks after planting) by cutting close to the soil. Plants were placed in marked paper bags and over-dried at 65^{p} - 70^{o} C for five days. The oven-dried plants were then ground in a Wiley mill and stored in tightly sealed glass bottles.

One-node cuttings of Para grass were started on July 24, 1964 in moist paper towels and then planted on July 28 at the rate of 10 cuttings per pot. Pots were kept in the shade till shoots began coming out after which the pots were transferred to the greenhouse. The cuttings were thinned to 5 per pot on August 5,

TABLE IV. CONCENTRATIONS, ON MOIST SOIL BASIS, AND SOURCES OF MINERAL NUTRIENTS ADDED TO SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL

Element	Concentration	Source
	ppm	
N	100	Urea
K	200	KCl
Mg	50	$MgSO_4 \cdot 7H_2O$
Mn	10	$MnSO_4 \cdot H_2O$
Zn	10	$ZnSO_4 \cdot H_2O$

leaving more or less similar-sized shoots in all pots. Spraying was not necessary on Para grass. Harvesting was done on September 5 by cutting the plants close to the node of the original cutting. Harvested plants were treated in the same manner as the Sudan grass.

Lime-Phosphate Experiment

Sudan grass seeds were planted on July 30, 1964; first thinning was on August 4 and final, on August 6. The plants were harvested 6 weeks after planting.

Para grass cuttings were started on July 20, 1964 and planted on August 1. Plants were thinned on August 12 and harvested at the same age as in the silicate plots.

Check Pots

Three pots, to which no nutrient was applied, were provided for each grass by growing the seedlings or cuttings on perlite. This was done for the determination of seed phosphorus.

Analytical Methods

Soil pH. Water was added to field-moist soil, giving a 1:1 soil-water ratio. The mixture was stirred with a glass rod and after 30 minutes equilibration pH was read with a Beckman model N glass-electrode pH meter.

Phosphate-fixing capacity. The method described by Fox, et al (1962) was used with the following modifications: 20 ppm P solution was used instead of 4.4 ppm and a soil-solution ratio of 1:12.5 instead of 1:10. These modifications were made because Hydrol Humic Latosols have a very high phosphate fixing capacity (Chu and Sherman, 1952). The P solution was tagged with P^{32}.

Soil plus fertilizer phosphorus in the supernatant liquid was analyzed colorimetrically, using the chlorostanous-reduced molybdophosphoric blue color method in sulfuric acid system described by Jackson (1958). No phosphorus could be detected, indicating that the amount of phosphorus in the solution was too minute to be detected by this most sensitive of the colorimetric determinations. Fertilizer phosphorus (tagged with P^{32}) was determined by counting with an automatic sample changer and timer-printer equipped with a gas flow tube. The standard was recounted every 4 hours to correct for radioactive decay (Ballard and Dean, 1940).

Extractable phosphorus. Phosphorus was extracted by the Truog method modified by Ayres and Hagihara (1952). Colorimetric determination of phosphorus in the extract was made by the procedure used for soil plus fertilizer phosphorus already described.

Exchangeable cations. Exchangeable cations were extracted with neutral normal ammonium acetate described by Jackson (1958) except for the following modifications: 50 g moist soil were used for the zero- and two-ton lime levels and 25 g for higher levels. This was done because this soil has very little exchangeable bases, especially calcium (Ayres, 1943). For calcium and magnesium determinations, ammonium acetate in the extract was destroyed by Jackson's (1958) method modified to use 5 ml. aqua regia to destroy organic matter.

Calcium and magnesium were determined using the Versene or EDTA titration method as described by Chapman and Pratt (1961). Sodium and potassium were analyzed flame photometrically with a Beckman model DU spectrophotometer.

Total calcium. Total calcium in the zero- and five-ton lime levels of the low-lime profiles was determined by the oxalate method after precipitating the R_2O_3 from the residue.[2]

Extractable sulfur. Sulfur was extracted with water and by the method described by Fox, et al (1964), using 500-ppm P from potassium dihydrogen phosphate at a soil-solution ratio of 1:5 and 30 minutes shaking. Sulfur in the extract was analyzed turbidimetrically using the procedure described by Chesnin and Yien (1950).

Extractable silicon. Silicon was extracted with a method devised by Fox (1965, unpublished) as follows:

Preparation of the Extractant:

(1) Acetic acid solution (0.1N) was prepared which also contained 500 ppm phosphorus from $Ca(H_2PO_4)_2 \cdot H_2O$.

(2) Ammonium acetate (o.1N) was prepared which also contained 500 ppm phosphorus. The pH of this solution was adjusted to about neutral with the acetic acid solution prepared in step (1).

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[2]Analysis was done by Mrs. Annie Chang of the Department of Agronomy and Soils.

(3) Solutions (1) and (2) were mixed and the pH of the final solution adjusted to exactly 3.5 with increments of either of the solutions. The extracting solution was stored in polyetheylene bottles to prevent contamination of silicon from the container.

Extraction:

(1) Ten g field-moist soil were weighed into a 250 ml Erlenmeyer pyrex flask and then 100 ml of the extractant was added.

(2) The flask was stoppered tightly with a rubber stopper, shaken for 4 hours and then the extract filtered through a Whatman No. 42 filter paper into a plastic vial.

Color Development:

(1) A 5 ml aliquot of the extract was pipetted into a 50 ml volumetric pyrex flask and made to about 40 ml with distilled water.

(2) Fout ml of 10% ammonium molybdate (saturated solution) were added and then 1 ml of 12N H_2SO_4. These reagents were added with force which gave better mixing and reduced time lag between applications of molybdate and sulfuric acid.

(3) Color developed for 10 minutes.

(4) Three ml of 10% oxalic acid (saturated solution) were added with force, the volume made up to 50 ml with distilled water and the flask inverted several times.

(5) Color was read in the colorimeter about 2 minutes after adding the oxalic acid at 430 millimicrons wavelength.

Preparation of Standard Curve:

(1) Quartz sand was acid-washed several times and then fused. A solution containing 100 ppm silicon was prepared.

(2) A solution containing about 100 ppm silicon from sodium silicate was prepared and standardized with the silicon solution from fused quartz sand. This solution became the working standard.

(3) Suitable aliquots of the sodium-silicate working standard solution were pipetted into 50 ml volumetric pyrex flasks, blank extract added, and color developed and determined according to the steps in Color Development.

Determination of extractable silicon with this method was found to be very sensitive to seed-crystal contamination so that all glassware were washed with dilute hydrochloric acid (1:20), washed with tap water, rinsed with 1:10 ammonium hydroxide and then washed with distilled water.

Cation exchange capacity. Cation exchange capacity of composited samples of TVA slag-treated plots was determined using ammonium acetate (Jackson, 1958) and unbufferred N ammonium chloride (pH 5.1) for saturating the soil colloids with NH_4^+. Ammonium nitrogen was distilled using the Kjeldahl method.

Extractable aluminum. Extractable aluminum in the surface-soil of the TVA slag and lime-phosphate plots was analyzed by the method described by Fox, et al (1962) using N $BaCl_2$ (pH 4.0) at two-hous fast shaking.

Profile studies. Soil pH was determined in all profile samples. Cation exchange capacity and exchangeable cations were analyzed in the zero- and 17-ton lime profile samples of the lime-phosphate experiment using both ammonium acetate and ammonium chloride. Exchangeable bases were determined in the low-lime experiment using ammonium acetate for displacement of exchangeable cations. All profile determinations, except pH, were made on composited samples.

Plant Analysis

Total and fertilizer nutrient uptake. Dry-ashing of plant samples as described by Chapman and Pratt (1961) was used for phosphorus, calcium, magnesium, sodium and potassium. Fertilizer phosphorus in plants was determined in similar manner as in the soil phosphate fixation studies. Total plant phosphorus was determined by the vanadomolybdophosphoric yellow color method of Kitson and Mellon (1944) with Barton's modification. Calcium and magnesium were determined by EDTA titration and sodium and potassium, with the Coleman Junior flame photometer.

Wet digestion with 2:1 nitric-perchloric acid (a modification of the method described by Piper, 1950) was used for determining plant sulfur and silicon. Sulfur was determined turbidimetrically by the method of Chesnin and Yien (1950) and silicon, gravimetrically as follows:

The residue of the wet digestion was collected on No. 42 Whatman filter paper, washed 10 times with small aliquots of warm distilled water and the filter paper (with the SiO_2) was placed in preignited and tared porcelain crucible.

The filter paper in the crucible (with the SiO_2) was ignited at 400° C overnight in a muffle furnace. The residue was cooled in a dessicator and then weighed.

RESULTS AND DISCUSSION

Effects of Silicates and Carbonates on pH and Mineral Nutrients in the Soil

Soil reaction. The chemical reactions involved in raising soil pH when carbonate is applied to acidic soils are quite clearcut. But the exact mechanics of the effect of silicate in increasing soil pH has not been clearly established. However, this effect may be due to the hydrolysis of Ca-clay as in the case of liming acidic soils with calcium carbonate, in the following chemical reactions:

$$CaCO_3 + 2H\text{-clay} \longrightarrow Ca\text{-clay} + H_2O + CO_2$$

In this case Ca-clay may be hydrolyzed as follows:

$$Ca\text{-clay} + 2H_2O \longrightarrow 2H\text{-clay} + Ca(OH)_2$$

The end-product $Ca(OH)_2$ would then increase the pH of the soil solution. In the absence of definite chemical reactions involved when calcium silicate is applied to acidic soils, the following may be offered to help explain its effect in modifying soil pH:

$$CaSiO_3 + \begin{matrix} Al\text{-} \\ Fe\text{-clay} \\ H\text{-} \end{matrix} \longrightarrow Ca\text{-clay} + (Al^{+++},\ Fe^{++},\ H^{+})\,SiO_3^{--}$$

Hydrolysis of Ca-clay may then occur as in the case of calcium carbonate application. The reactions of $CaSiO_3$ in acidic soils as stated here are in very general terms, especially the end-products which could be an array of silicate compounds. However, it may be of interest to note that SiO_3^{--} could immobilize aluminum and iron in acidic soils.

In this experiment TVA slag was a very effective liming material. Eight tons of slag were sufficient to raise soil pH from about 5.4 to 6.7 seven months after application. In contrast, volcanic cinders were totally ineffective in changing soil pH--an indication that this material weathered very little in the soil. These two silicate carriers are compared at equivalent rates of silicon in Table V. Evidently, TVA slag could favorably compare with other liming materials in raising soil pH. Bear (1955) stated that better quality slags used for liming have neutralizing values of 70% to 80% that of limestone.

TVA slag, no doubt, immobilized active aluminum and iron in this acid soil and thus decreased phosphate fixation by these cations as stated by Kelly and Midgley (1943) and other workers. Perhaps TVA slag has a "double-barreled" effect on the efficiency of phosphate utilization by plants: first, prevention of phosphate fixation by immobilizing aluminum and iron and second, release of fixed phosphate by anion exchange between phosphate and silicate as suggested by Peck (1911). However, if such is the case the effect is probably short-lived as will be demonstrated later.

Four years following coral stone and phosphate application soil pH varied, according to the amount of lime applied, from 5.1 to 7.5 in the zero-phosphate plots and from 5.0 to 7.3 in the plots receiving 176 lb/A of P (Table VI).

Although there was a significant interaction between lime and phosphate at the 1% level, it can be seen from the large variance for lime that, relatively,

TABLE V. EFFECT OF SILICATE MATERIALS ON pH OF AKAKA SURFACE SOIL[1]

Silicate carrier	Si rates applied (T/A)				
	0	0.35	0.70	1.05	1.40
TVA slag	5.4	6.1	6.2	6.3	6.7
Volcanic cinders	5.4	5.4	5.7	5.4	5.3
Volcanic cinders + coral stone	5.4	5.8	6.2	6.4	6.7

Analysis of Variance

SV	df	MS
Replications	3	0.04
Treatments	(14)	(1.02)
Carriers (C)	2	3.06*
Levels (L)	4	1.28 n.s.
C x L	8	0.38**
Error	42	0.03

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table I.

TABLE VI. EFFECT OF LIME AND PHOSPHATE ON pH OF AKAKA SURFACE SOIL[1]

P applied lb/A	Lime applied (T/A)			
	0	2	0.5	17
0	5.1	5.5	6.9	7.5
88	5.4	5.8	7.0	7.2
176	5.0	5.5	6.4	7.3

Analysis of Variance

SV	df	MS
Replications	3	0.0209
Phosphate (P)	2	0.3010 n.s.
Lime (L)	3	11.4840**
P x L	6	0.1323**
Error	33	0.0387

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table II.

there was little effect of phosphate on soil pH. Rixon and Sherman (1963) obtained a pH of about 6.3 from the highest lime rate in this experiment three months after application of coral stone. This indicates a fairly rapid decomposition of coral stone in this soil.

Soil reaction in the profile of the low-lime experiment is shown in Figure 1 and Table VII. Seven years after 5 tons of coral stone had been applied, modification in soil pH could still be detected at all depths in the profile. These differences were not significant between levels of lime but were statistically highly significant between depth increments. Soil pH increased with depth regardless of previous lime applications--particularly the zero-lime plots. Since organic matter decreases with depth, it is probably that low pH of the surface horizon was associated with organic matter which is relatively high in the surface of this soil. In the limed plots it is possible that continuous decomposition of lime in the surface soil and its movement downward caused the pH at lower depths to increase (Brown and Munsell, 1936 and Pearson, et al 1962).

It is evident that calcium leaches quite readily in this soil even though cation exchange capacity is high. Even so, 5 tons of lime still exerted an influence on pH of the surface after seven years.

Liming effects were much more obvious on plots which were limed in 1959 than those limed in 1956. Whereas the effect of 2.5 tons of lime applied in 1956 was to increase soil pH from 4.7 to 4.9, 2 tons applied in 1959

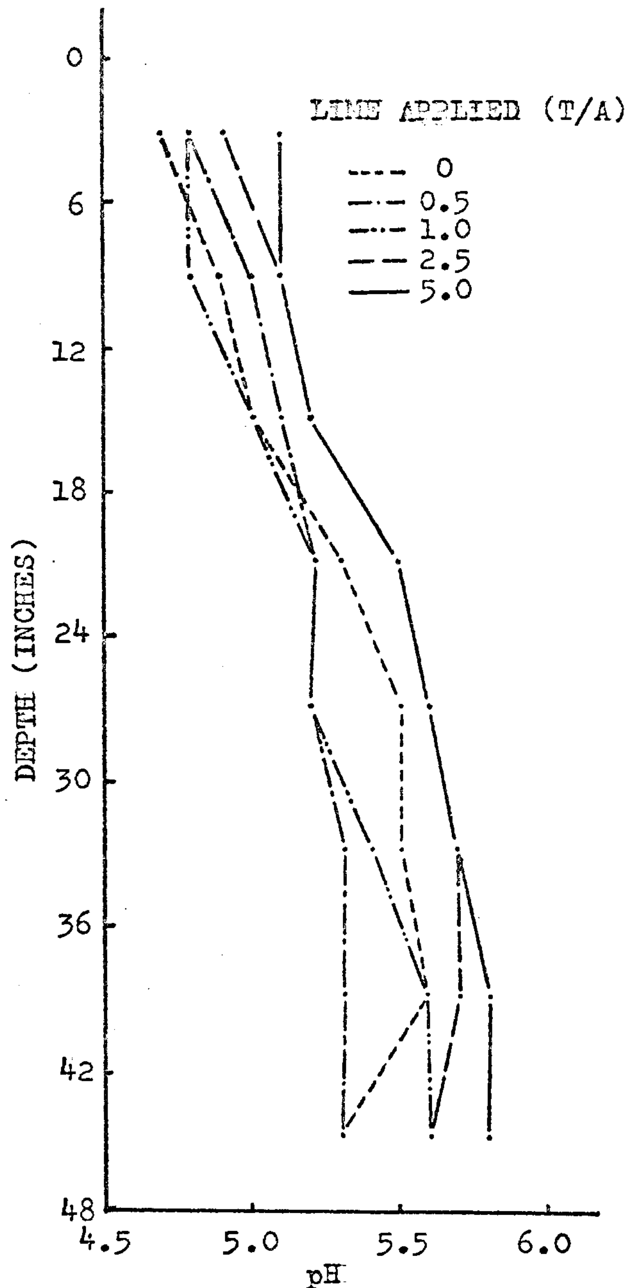

FIGURE 1. EFFECT OF LIME APPLIED IN 1956 ON pH OF AKAKA SOIL PROFILE IN 1963

TABLE VII. EFFECT OF LIME APPLIED IN 1956 ON THE pH OF PROFILES OF AKAKA SOIL SAMPLES IN 1963[1]

Depth (in.)	Lime applied (T/A) 0	0.5	1.0	2.5	5.0
0- 6	4.7	4.8	4.8	4.9	5.1
6-12	4.9	5.0	4.8	5.1	5.1
12-18	5.0	5.1	5.0	5.2	5.2
18-24	5.3	5.2	5.2	5.5	5.5
24-30	5.5	5.2	5.2	5.6	5.6
30-36	5.5	5.3	5.4	5.7	5.7
36-42	5.6	5.3	5.6	5.7	5.8
42-48	5.3	5.3	5.6	5.6	5.8

Analysis of Variance

SV	df	MS
Replications	2	0.1620
Treatments	(39)	(0.2711)
Levels (L)	4	0.5636 n.s.
Depths (D)	7	1.0833**
LxD	28	0.0262
Error	78	0.0448

Rp values for Duncan's Test

p	2	3	4	5	6	7	8
Rp: 5%	0.35	0.36	0.38	0.38	0.39	0.40	0.40
1%	0.46	0.48	0.49	0.50	0.51	0.52	0.52

[1]Values are means of 3 replications, moist basis; for replicates and dry matter content of thesoil, see Appendix Table III.

increased pH from 4.8 to 5.3 in 1963. Soil pH in the profile of the 1959 lime applications is shown in Figure 2 and Table VIII.

Lime applied in 1959 resulted in appreciable changes in subsoil pH (Figure 2 and Table VIII). A statistically highly significant increase in pH was associated with lime levels as well as with depth increments in the profile. The influence of lime on the subsurface was related to the amount of lime applied. Even the use of 2 tons lime apparently resulted in some subsoil pH changes. These results are in keeping with those observed for plots limed in 1956.

Coral lime will not leach in quantity until it has reacted with acids of the soil or soil solution. This may take a considerable time, depending upon the fineness of the material. Even if calcium is in the ionic state rapid leaching can not be expected if cation exchange processes are operating normally. The fact that so much leaching occurred during the four years since the application of limestone is an indication that calcium is held very loosely by colloids of the Akaka soil. If results from the low-lime plots are an indication, leaching from these more recently limed plots may be more rapid in the future than in the past.

Evidently, the lime requirement of this soil was exceeded by the highest (17 T/A) rate of liming. At the time soil samples were collected rather large amounts of unreacted lime remained in the highest lime treatment; a little in the 9.5-ton treatment; while none was evident at 2 tons.

The profile pH associated with the 2-ton lime rate shown in Figure 2 strongly suggests that the first increment of calcium may be more tightly held

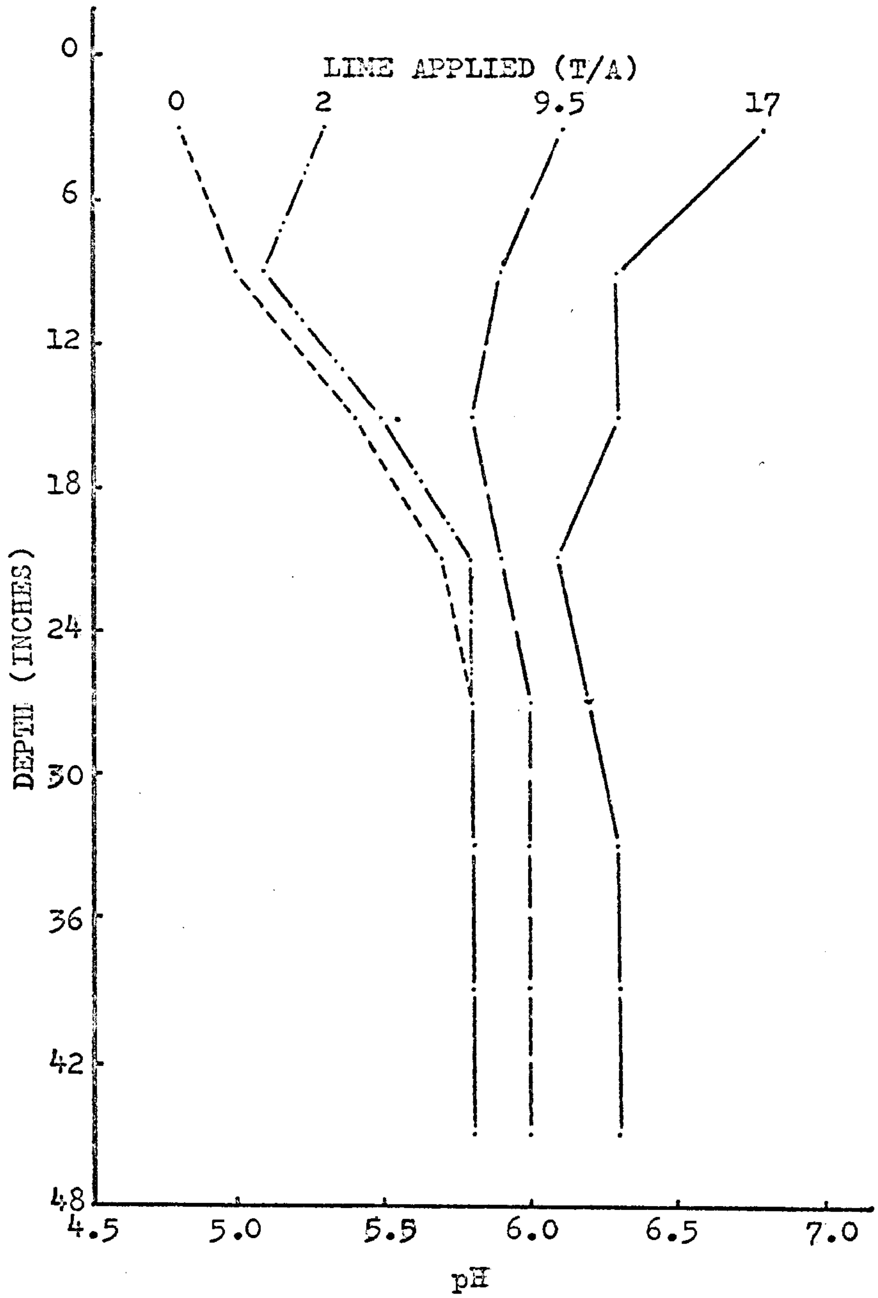

FIGURE 2. EFFECT OF LIME APPLIED IN 1959 ON pH OF AKAKA SOIL PROFILE IN 1963

TABLE VIII. EFFECT OF LIME APPLIED IN 1959 ON THE pH OF PROFILES OF AKAKA SOIL SAMPLES IN 1963[1]

Depth (in.)	0	2	9.5	17
0- 6	4.8	5.3	6.1	6.8
6-12	5.0	5.1	5.9	6.3
12-18	5.4	5.5	5.8	6.3
18-24	5.7	5.8	5.9	6.1
24-30	5.8	5.8	6.0	6.2
30-36	5.8	5.8	6.0	6.3
36-42	5.8	5.8	6.0	6.3
42-48	5.8	5.8	6.0	6.3

Analysis of Variance

SV	df	MS
Replications	3	0.0642
Treatments	(31)	(0.6691)
Levels (L)	3	4.3368**
Depths (D)	7	0.6507**
LxD	21	0.1513**
Error	93	0.0283

Rp values for Duncan's Test

p	2	3	4	5	6	7	8
Rp: 5%	0.27	0.28	0.29	0.30	0.31	0.31	0.31
1%	0.36	0.37	0.38	0.39	0.40	0.40	0.40

[1]Values are means of 4 replicates, moist basis. For replicates and dry matter content of the soil, see Appendix Table IV.

than later increments. The 9.5- and 17-T/A rates remarkably increased the pH of the subsoil as well as the surface soil. Evidently, appreciable quantities of calcium bicarbonate moved from the surface downward to cause measurable increase in pH at the lower depths.

The decreasing trend of pH from the surface down to 6-12, 12-18 and 18-24 inches for the 2-, 9.5-, and 17-T/A rates of limes, respectively, could be due to any or both of the following: (1) the considerable increase in surface-soil pH caused the reaction to increase downward, and (2) neutral salts at the surface formed as a result of liming moved down to these depths, causing a depression in pH (Brown and Munsell, 1936; Raupach, 1957; and Pearson, et al 1962). These investigators leached the subsoil showing the lowest pH and obtained an increase in pH of 0.4 to 0.6 units.

Surface soil pH values reported in Table VI are higher than the 0-6 inch increment of the profiles reported in Table VIII. These data are from different samples taken from the same plots. This could be due to one or both of the following causes: (1) In the profile samples presented in Table VIII, the amount of soil taken from the surface downward was uniform; whereas in the surface soil samplings with a spade, more surface soil could have been taken relative to the immediate subsurface. More undecomposed lime came with the sample which continued decomposition in the stored moist samples. (2) Surface soil pH was determined about two months after the profile samples. During this time there could have been continued decomposition of lime, with no leaching, in the moist surface soil samples.

Phosphate fixation. That the phosphate fixing capacity of this soil is very high is shown in Table IX. A 20-ppm P solution tagged with P^{32} was equilibrated with soil using a soil-solution ratio of 1:12.5, moist basis (the soil had about 40% dry matter). The phosphate remaining in solution was measured in parts per billion (ranging from about 2 to 6 ppb). Detection of such very minute amounts of phosphorus would have been impossible had it not been for the use of radioisotope tracer techniques. Colorimetric determination (Jackson, 1958) of total phosphorus in the solution failed to detect any phosphorus even when the most sensitive chemical method was used.

For practical purposes all of the fertilizer phosphorus added was fixed. Six ppb P^{32} left in solution from 20 ppm indicates about 99.97% fixation even when the highest rate of slag was used.

More phosphorus remained in solution when phosphorus was equilibrated with soils which had been treated with slag than when control soils were equilibrated with phosphorus solutions. Although these differences were minute in quantity they were statistically highly significant. To some degree, increasing rates of slag decreased phosphorus fixation. This decrease could not have been due to pH but to increasing silicate which may have substituted for phosphate in the exchange sites. The pH of the TVA slag plots and that of the mixture of cinders and coral stone (Table V) were practically the same and yet there was no measurable difference in the amount of phosphorus remaining in

TABLE IX. FERTILIZER PHOSPHORUS REAMINING IN SOLUTION AFTER 48 HOURS WHEN 20 PPM P SOLUTION WAS EQUILIBRATED WITH AKAKA SOIL WHICH HAD BEEN TREATED WITH VARIOUS SILICATE CARRIERS[1]

Silicate carrier	Si applied (T/A) 0	0.35	0.70	1.05	1.40
	ppb				
TVA slag	1.6	4.0	3.9	3.5	5.6
Volcanic cinders	2.8	2.3	2.3	2.1	2.7
Volcanic cinders + coral stone	2.1	2.1	2.2	1.8	3.4

Analysis of Variance

SV	df	MS
Replications	3	0.4678
Treatments	(14)	(4.6852)
Carriers (C)	2	11.9330*
Levels (L)	4	5.4210 n.s.
C x L	8	2.5054**
Error	42	0.7391

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table V.

solution between the check and the highest rate of the mixture of cinders and coral stone. Presumably, the cinders in the mixture did not release sufficient silicate to effect anion exchange. More evidence to this effect will be presented later.

Extractable phosphorus. Extractable phosphorus apparently increased with increasing rates of TVA slag (Table X). Although this trend did not reach statistical significance, it was consistent in all replications (Appendix Table 6). Volcanic cinders had no effect. Effects of these two silicate carriers on extractable phosphorus are shown in Table X. These results correspond with increasing amounts of phosphorus remaining in solution with increasing rates of slag (Table IX). This may account for the increasing trend of extractable phosphorus in the slag plots--an indication of decreased phosphate fixation as a result of slag treatment.

It is evident from the data presented in Figure 3 and Table XI that liming influenced soil phosphorus (original phosphorus) quite differently from fertilizer phosphorus applied at the time of liming. Thus, when no fertilizer phosphorus was applied extractable phosphorus decreased with increasing liming rates but the trend was for increased phosphorus extraction with increasing liming when the highest rate of phosphorus was applied. It is assumed that in this soil phosphorus was present in the form of iron and aluminum phosphate. When the soil was limed aluminum and iron must have precipitated out of solution; perhaps on the iron and aluminum phosphates, rendering them

TABLE X. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXTRACTABLE PHOSPHORUS FROM AKAKA SOIL[1]

Silicate carrier	Si applied (T/A) 0	0.35	0.70	1.05	1.40
	ppm				
TVA slag	3.8	4.3	5.3	7.8	6.3
Volcanic cinders	5.7	6.8	5.7	4.6	6.0

Analysis of Variance

SV	df	MS
Replications	3	0.8666
Treatments	(9)	(5.7972)
Carriers (C)	1	0.7426
Levels (L)	4	2.7829
C x L	4	10.0752**
Error	27	0.5170

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil see Appendix Table VI.

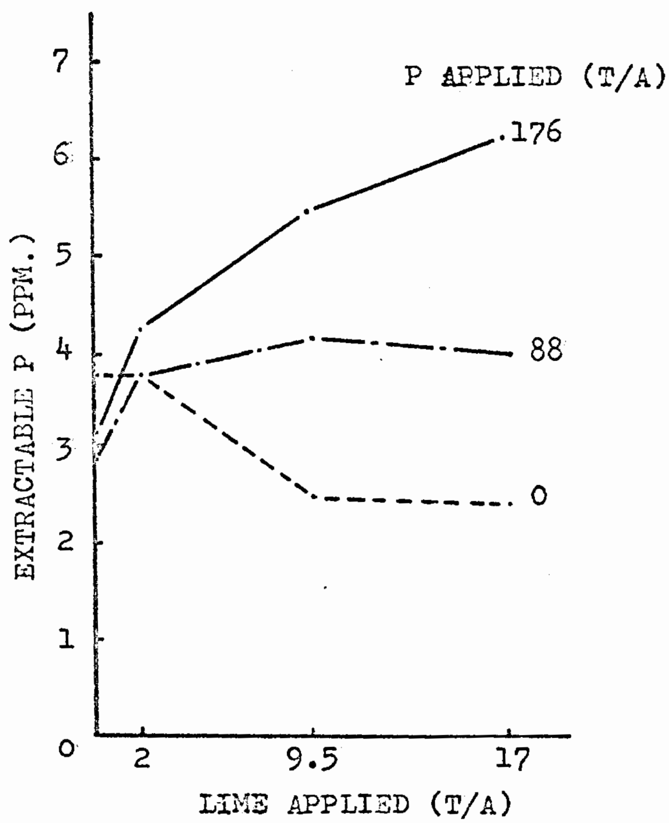

FIGURE 3. INFLUENCE OF LIME AND PHOSPHATE ON EXTRACTABLE P IN AKAKA SOIL 4 YEARS AFTER APPLICATION

TABLE XI. EFFECT OF LIME AND PHOSPHATE ON EXTRACTABLE PHOSPHORUS FROM AKAKA SOIL USING TRUOG MODIFICATION A (AYRES AND HAGIHARA, 1952)[1]

P applied	Lime applied (T/A)			
	0	2	9.5	17
(lb/A)	ppm			
0	3.7	3.7	2.5	2.4
88	2.9	3.7	4.0	3.9
176	3.2	4.2	5.4	6.2

Analysis of Variance

SV	df	MS
Replications	3	0.2335
Phosphate (P)	2	11.1546 n.s.
Lime (L)	3	1.8493
P x L	6	4.3248
Error	33	0.2871

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table VII.

less soluble. When phosphorus fertilizer was added to the limed soil, phosphorus was precipitated as calcium phosphate in proportion to the rate of liming. Calcium phosphate is more soluble in dilute acid than iron and aluminum phosphate. These results indicate that liming may have an adverse effect on soil phosphorus extractability and at the same time promote the extractability of fertilizer phosphorus added concurrently with lime.

Liming this highly acidic soil must have caused formation of slightly insoluble calcium phosphate as stated by Scheffer and Schulz (1955). However, once the phosphate was already precipitated as iron or aluminum phosphate it could no longer form the less soluble calcium phosphate. Phosphorus eventually "ended up" in its least soluble or most stable form. These data do not lend support to the idea that liming will increase the solubility of native iron and aluminum phosphates.

Exchangeable calcium. Exchangeable calcium appreciably increased with increasing TVA slag rates (Table XII) while the effect of volcanic cinders was practically nil. This increase in exchangeable calcium in the slag plots corresponded to increasing amounts of calcium present in the slag. As shown in Table I the slag contained 29.8% CaO equivalent, which is equivalent to 35.6% calcium. At the slag rate of 2 tons, calcium added to the soil through the slag was 0.71 ton; and at 8 tons slag, calcium added was about 2.85 tons or about 14 me/100 g on assuming 2×10^6 pounds of soil per acre. Since much less calcium was recovered than was added it seems likely that some calcium had been leached.

TABLE XII. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE CALCIUM IN AKAKA SOIL[1]

Silicate carrier	Si applied (T/A)				
	0	0.35	0.70	1.05	1.40
	me/100 g				
TVA slag	0.44	1.70	3.18	4.60	5.78
Volcanic cinders	0.31	0.36	0.42	0.49	0.42

Analysis of Variance

SV	df	MS
Replications	3	0.0899
Treatments	(9)	(16.4600)
Carriers (C)	1	74.9858*
Levels (L)	4	9.7093 n.s.
C x L	4	8.5792**
Error	27	0.0719

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil see Appendix Table VIII.

In the lime-phosphate experiment, increasing lime greatly increased the amount of exchangeable calcium in the soil as shown in Figure 4 and Table XIII. As indicated in the figure the amount of exchangeable calcium generally decreased with increasing increments of phosphate. This probably indicates that phosphate "tied up" calcium as the phosphate of relatively low solubility. It is also possible that phosphate formed coatings on the lime particles thus retarding their dissolution.

The almost linear trend of decreasing exchangeable calcium with increasing phosphate at the lower lime levels is an indication that phosphate immobilized calcium as stated by Coleman (1960).

It is of interest to note in this experiment that the amount of exchangeable calcium abruptly increased from the 2- to the 9.5-ton rates with a very small increase from 9.5 to 17 tons per acre of lime. Evidently, this soil could be saturated with calcium at about 10 tons lime per acre so that as far as liming for calcium saturation is concerned, rates higher than 10 tons were in excess. Lime greater than 10 tons would probably remain as free carbonate and reduce considerably the amount of available phosphate and some micronutrients in the soil.

Clements (1962) reported that the calcium requirement for sugar cane was satisfied if this soil was limed with 2 tons per acre of coral stone. Yet, yield response was obtained up to 10 T/A of lime. Evidently, there were benefits from lime other than supplying calcium.

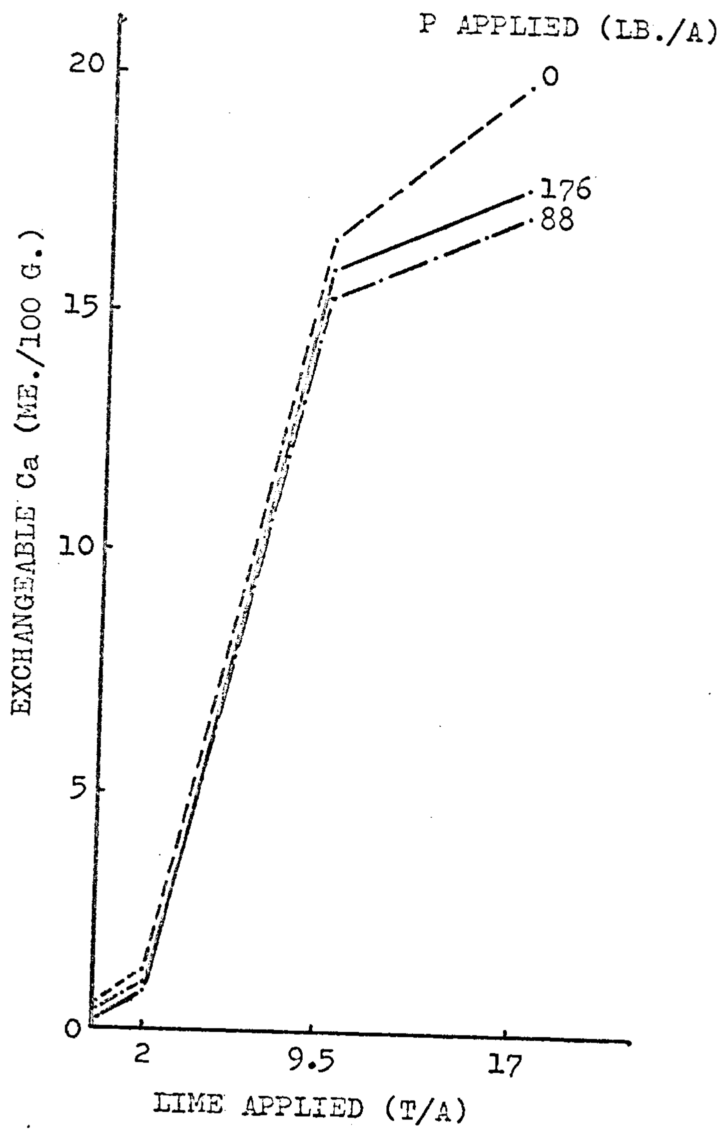

FIGURE 4. INFLUENCE OF LIME AND PHOSPHATE ON EXCHANGEABLE Ca IN AKAKA SOIL 4 YEARS AFTER APPLICATION

TABLE XIII. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE CALCIUM IN AKAKA SOIL[1]

P applied	Lime applied (T/A)			
	0	2	9.5	17
(lb/A)	me/100 g			
0	0.51	1.20	16.57	19.85
88	0.43	0.95	15.30	17.04
176	0.27	0.88	15.84	17.65

Analysis of Variance

SV	df	MS
Replications	3	0.4971
Phosphate (P)	2	5.42.4 n.s.
Lime (L)	3	1078.2838**
P x L	6	1.7136
Error	33	0.6980

[1] Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table IX.

Benefits from decreased toxicity of aluminum, iron and manganese are possible but do not seem likely since 2 tons was sufficient to raise the pH of the soil to above pH 5.0 throughout the profile. Rixon and Sherman (1963) obtained a significant negative correlation between extractable aluminum and exchangeable calcium with increasing rates of lime applied to the soil.

Exchangeable calcium in the profile of the check plot of the lime-phosphate experiment showed a more or less similar pattern for both ammonium acetate and ammonium chloride extractants (Figure 5 and Appendix Table X), although ammonium chloride gave slightly higher values than ammonium acetate. What probably happened was that in the unbuffered ammonium chloride system, iron and aluminum were extracted in quantities sufficient to interfere with the EDTA titration (Jackson, 1958). This then increased slightly the amount of EDTA required for titration due to the masking effect of both metals on the reaction of calcium with the EDTA.

There was not much difference between the values for exchangeable calcium in the high-lime plot in both extractants. This seems to substantiate the statement about interference by iron and aluminum. The high-lime treatment must have precipitated iron and aluminum so that interference was negligible.

Exchangeable calcium was increased throughout the four-foot profile as a result of applying 17 tons of lime (Figure 5). Although only four years had elapsed since lime had been applied, leaching was well advanced. The amount of exchangeable calcium at the top six inches of soil in the 17-ton treatment is only

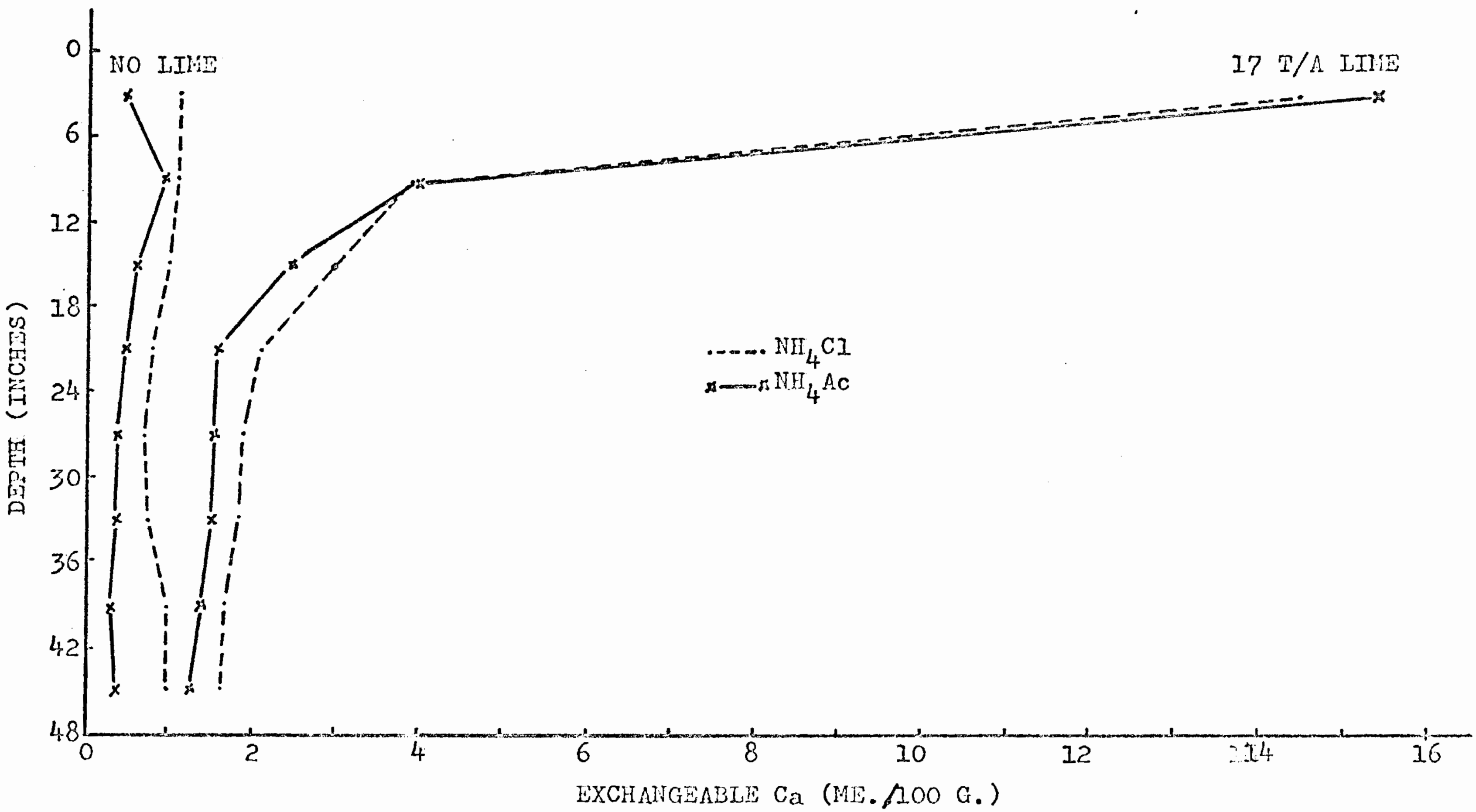

FIGURE 5. EFFECT OF HEAVY LIME APPLICATION ON EXCHANGEABLE Ca IN AKAKA SOIL PROFILE APPLIED FOUR YEARS BEFORE SAMPLING

about 50% of the amount of calcium applied to the soil. Much of the calcium not recovered must have been leached.

Seven years after low-lime plots had been limed with coral stone only slightly higher values of exchangeable calcium could be detected throughout the profile. This is shown in Figure 6 (Appendix Talbe 11). However, the difference between the highest rate (5 T/A) and the lesser rates of lime was small. Evidently, most of the calcium had been leached out since total calcium in the profile was not increased measurably.

Extractable aluminum. TVA slag effectively decreased extractable aluminum from 3.11 me/100 g for the check to 0.44 me/100 g for the 8-ton rate (Figure 7 and Appendix Table 12). This decrease could be due to: (1) precipitation of aluminum by increasing pH that accompanied increasing slag rates and/or (2) formation of alumino- and ferro-silicates in the soil system.

Lime interacted with phosphate in the lime-phosphate experiment resulting in slightly higher extractable aluminum values with increasing phosphate at the higher lime rates (Figure 8 and Appendix Table 13). It may be recalled that the trends of pH in these plots (Table VIII) were the reverse of the pattern for extractable aluminum shown in Appendix Table 13. The decreases in extractable aluminum from about 3.0 me/100 g in the 0-0 plots to around 0.5 me/100 g in the high-lime- and high-phosphate plots may be due to one or both of these effects: (1) pH effect and (2) precipitation of aluminum by phosphate into the highly insoluble aluminum phosphate.

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[1]Personal communication with Mrs. Annie Chang who made the determination for total calcium in these profiles.

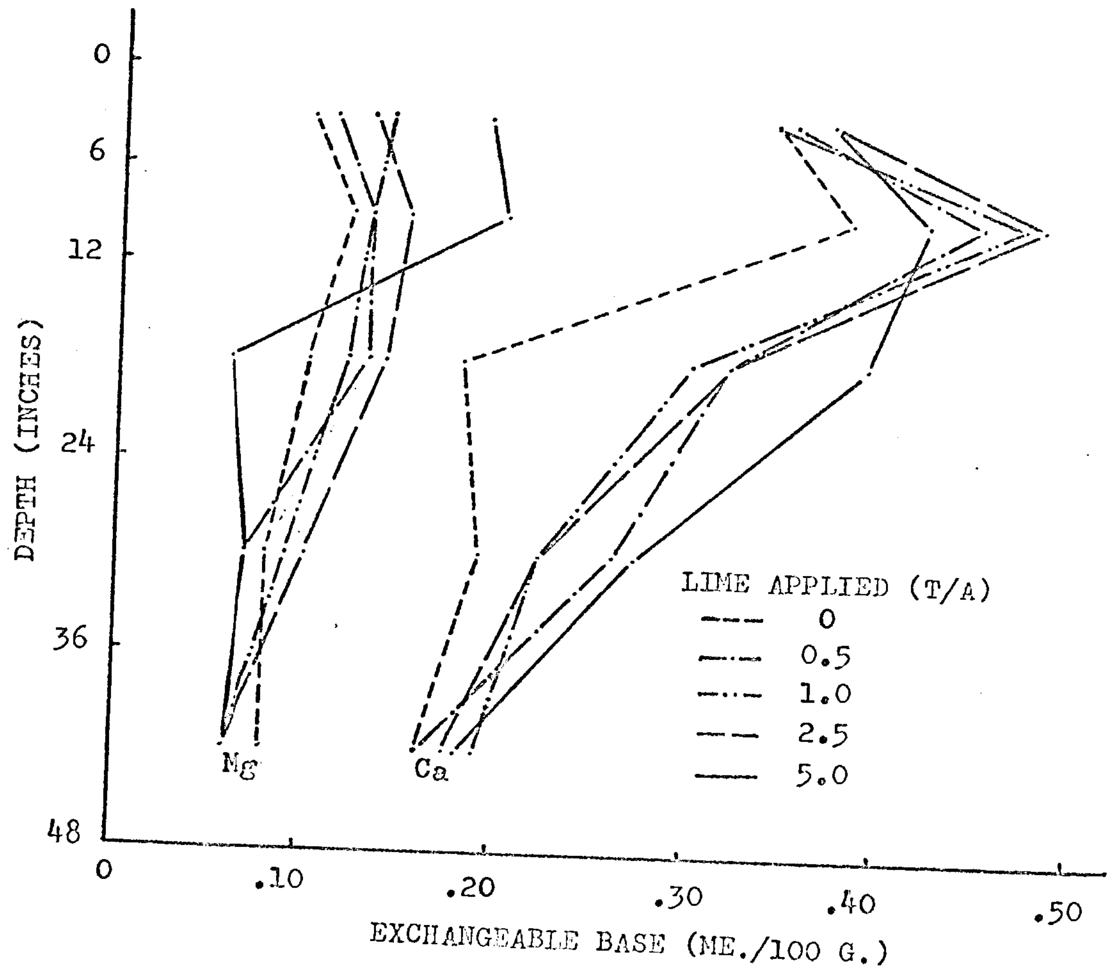

FIGURE 6. INFLUENCE OF LOW-LIME APPLICATIONS ON EXCHANGEABLE Ca AND Mg IN AKAKA SOIL PROFILES

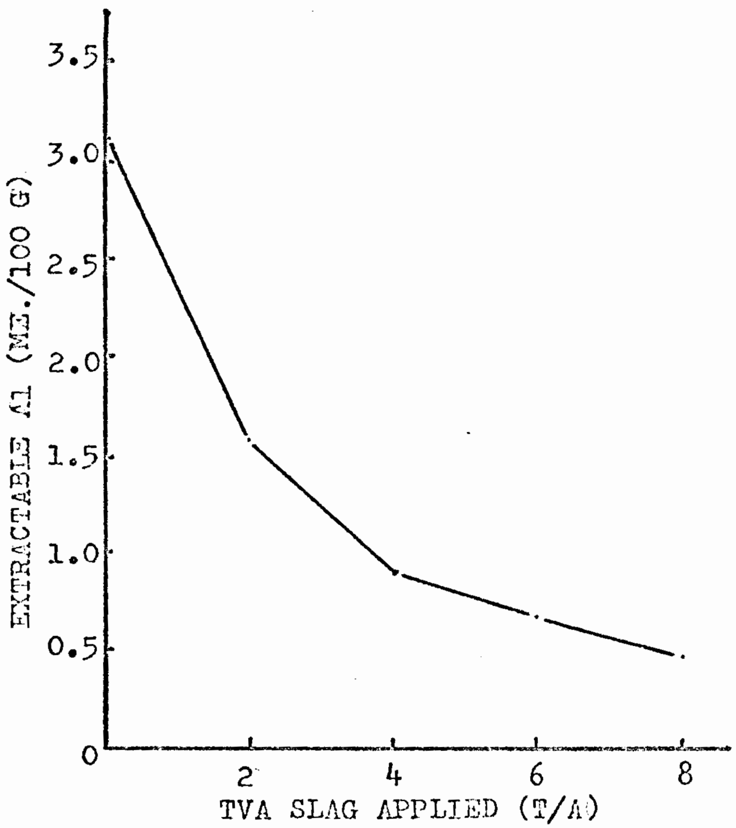

FIGURE 7. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON EXTRACTABLE ALUMINUM IN AKAKA SOIL

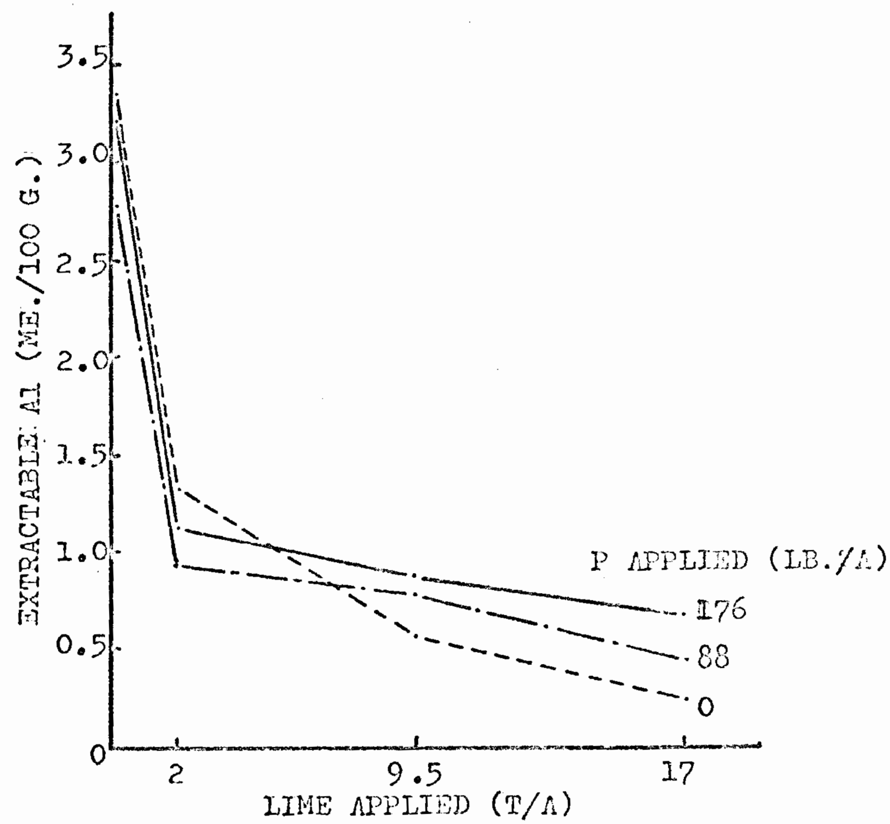

FIGURE 8. EFFECTS OF LIME AND PHOSPHATE ON EXTRACTABLE ALUMINUM IN AKAKA SOIL

Exchangeable magnesium. TVA slag greatly influenced the amount of exchangeable magnesium in the soil while volcanic cinders had, at the greatest, only slight effect. Effects of these two siliceous materials are compared in Table XIV.

Increasing amounts of exchangeable magnesium with increasing slag may be partly due to magnesium in the slag which had been solubilized and adsorbed by the soil. Table I shows 0.4% MgO equivalent in TVA slag. This, however, could account for no more than about 0.1 me/100 g of exchangeable magnesium. Evidently, much of the magensium shown in the increasing trend with increasing slag must have come from the soil.

In the lime-phosphate plots exchangeable magnesium was increased by all levels of lime as shown in Figure 9 and Table XV. Again part of this increase may be due to magnesium in the coral stone which was 0.4%-0.7% MgO equivalent (Table II). Even this is insufficient to account for the increased exchangeable magnesium. These results may indicate difficulty in the EDTA titration. If not, they may indicate that soil magnesium must have been solubilized by lime.

It is also interesting to note that increasing rates of phosphate increased the amount of exchangeable magnesium in the soil (Table XV). Comparing this with the trend of exchangeable calcium which was decreasing with increasing phosphate (Table XIII) there seemed to be an inverse relationship between exchangeable calcium and magnesium in the soil.

TABLE XIV. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE MAGNESIUM IN AKAKA SOIL[1]

Silicate carrier	Si applied (T/A)				
	0	0.35	0.70	1.05	1.40
	me/100 g				
TVA slag	0.09	0.18	0.56	0.92	1.06
Volcanic cinders	0.08	0.12	0.13	0.13	0.12

Analysis of Variance

SV	df	MS
Replications	3	0.0025
Treatments	(9)	(0.5542)
Carriers (C)	1	1.9714 n.s.
Levels (L)	4	0.4011
C x L	4	0.3530**
Error	27	0.0012

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table XIV.

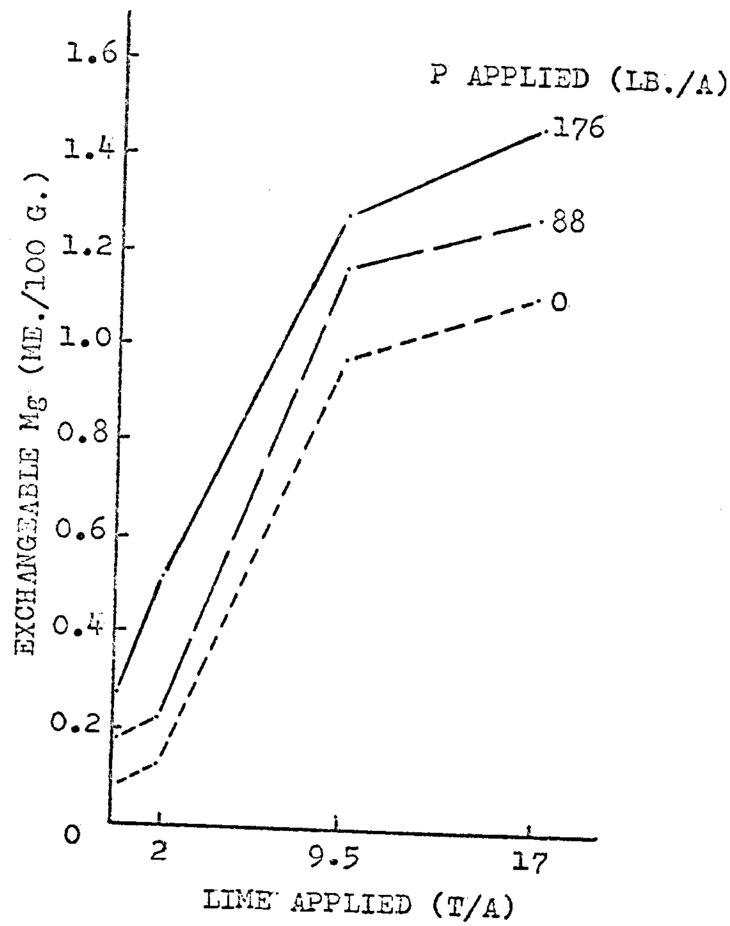

FIGURE 9. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE Mg IN AKAKA SOIL 4 YEARS AFTER APPLICATION

TABLE XV. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE MAGNESIUM IN AKAKA SOIL[1]

P applied	Lime applied (T/A)			
	0	2	9.5	17
(lb/A)	me/100 g			
0	0.08	0.12	0.98	1.17
88	0.18	0.22	1.17	1.28
176	0.28	0.52	1.28	1.47

Analysis of Variance

SV	df	MS
Replications	3	0.0149
Phosphate (P)	2	0.0450 n.s.
Lime (L)	3	4.0053**
P x L	6	0.1187**
Error	33	0.0159

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of soil, see Appendix Table 15.

Exchangeable magnesium in the upper 36 inches of the unlimed profile (lime-phosphate experiment) was greater than in the highest rate (Figure 10 and Appendix Table 10). Below 36 inches the amounts of exchangeable magnesium in the two treatments were comparable. This probably indicates that extremely high amount of calcium in the high-lime plot displaced the magnesium from the exchange sites in the upper depths. This displaced magnesium was either absorbed by plants or leached out of the profile. The uniform distribution of exchangeable magnesium with depth seems to bear this out (Figure 10).

All lime increments except the highest of the low-lime experiment resulted in slightly higher values of exchangeable magnesium over the control down to two feet deep (Figure 8, Appendix Table 11). The highest rates (5 T/A) had the greatest amount of exchangeable magnesium within the first foot, and the lowest rate, at the second foot depth. Since there was a corresponding increase in exchangeable calcium (Figure 8) at this depth it may be deduced that calcium replaced magnesium in the exchange site and the replaced magnesium was either absorbed by plants or leached down the profile. It is also possible that the determination of calcium was in error (error for calcium always leads to an opposite error in magnesium).

Exchangeable potassium. There was a consistent trend of increasing exchangeable potassium resulting from increasing rates of TVA slag although this trend failed to reach a statistically significant level (Table XVI). There

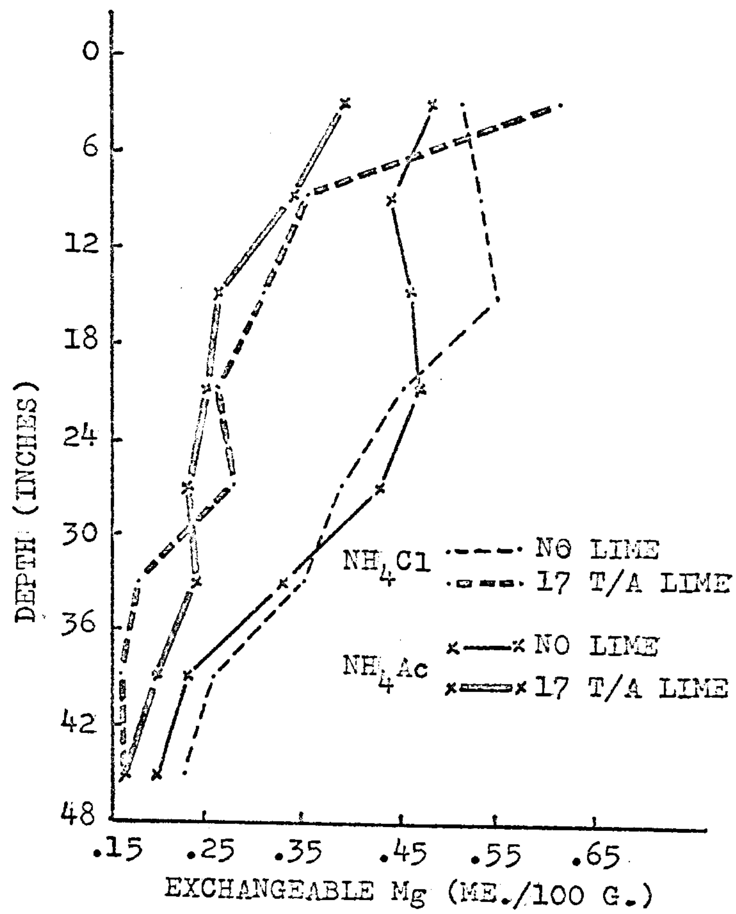

FIGURE 10. EFFECTS OF ZERO- AND 17-TON LIME APPLICATION ON EXCHANGEABLE Mg IN AN AKAKA SOIL PROFILE

TABLE XVI. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE POTASSIUM IN AKAKA SOIL[1]

Silicate carrier	Si applied (T/A)				
	0	0.35	0.70	1.05	1.40
	me/100 g				
TVA slag	0.06	0.08	0.12	0.11	0.14
Volcanic cinders	0.06	0.06	0.06	0.06	0.07

Analysis of Variance

SV	df	MS
Replications	3	0.000045
Treatments	(9)	(0.003493)
Carriers (C)	1	0.015602 n.s.
Levels (L)	4	0.002446
C x L	4	0.006048**
Error	27	0.000065

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table 14.

was no effect of volcanic cinders. In a slightly acid soil system where calcium is the dominant complimentary ion, it is probably that potassium and other weakly held cations are better able to compete for exchange sites than in an acid system where H^+ and Al^{+++} are the complimentary ions. Replacing tightly held complimentary ions (Al^{+++} and H^+) with the more weakly held calcium would promote retention of almost any exchangeable ion like potassium or sodium.

In the lime-phosphate experiment lime increased the amount of exchangeable potassium considerably while phosphate did not. Although there was a significant interaction between lime and phosphate, it can be readily seen in Table XVII that the influence of lime was relatively great.

Exchangeable potassium was not increased appreciably at the first two increments of lime but was increased measurably at the next two lime rates. This seems to substantiate the statements made earlier about effects of complimentary ions.

In the profile of the high-lime plots exchangeable potassium was concentrated in the surface. This is shown in Figure 11 and Appendix Table 10). The higher value for exchangeable potassium in the surface is probably due to the residual effect of frequent applications of potassic fertilizer but may also indicate recycling of potassium primarily by leaching from leaves. Ayres and Fujimoto (1944) found three patterns of distribution of exchangeable potassium in the profiles of Hawaiian lateritic soils: (1) decreasing with depth

TABLE XVII. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE POTASSIUM IN AKAKA SOIL[1]

P applied	Lime applied (T/A)			
	0	2	9.5	17
(lb/A)	me/100 g			
0	0.08	0.08	0.14	0.13
88	0.08	0.10	0.13	0.12
176	0.08	0.08	0.13	0.15

Analysis of Variance

SV	df	MS
Replications	3	0.000107
Phosphate (P)	2	0.000090n.s.
Lime (L)	3	0.010573**
P x L	6	0.000404**
Error	33	0.000084

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table 17.

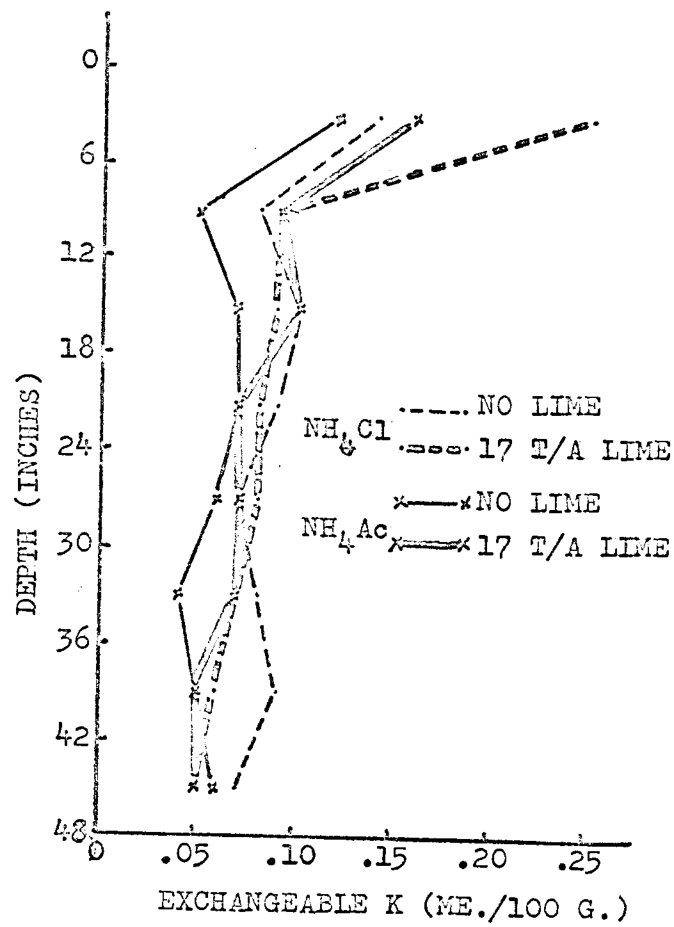

FIGURE 11. EFFECT OF ZERO- AND 17-TON LIME APPLICATION ON EXCHANGEABLE K IN AKAKA SOIL PROFILE

(down to as low as 84 inches); (2) decreasing downward to a point within the section and thereafter remained more or less constant; and (3) decreasing to 1 1/2 to 2 feet and then gradually increasing thereafter. Causes for these were attributed to: (1) recycling of soil potassium by plants (for patterns 1 and 2) and (2) removal by, and harvesting of, the crops grown (for the third pattern).

A different pattern for exchangeable potassium obtained in profiles from the low-lime plots. Highest values were obtained throughout the zero-lime profile (Figure 12 and Appendix Table 11). This may be explained by increased yields, thus greater potassium removal by crops from the limed plots.

The general trend in all plots was highest exchangeable potassium near the surface. This may be due to repeated applications of potassium fertilizers, recycling of potassium, or both.

Exchangeable sodium. Exchangeable sodium increased significantly with increasing rates of TVA slag. There seemed to be a slight increase in exchangeable sodium with increasing rates of cinders (Table XVIII) but the increase was not significant. This may be an indication that sodium-bearing minerals of the cinders weathered slightly.

Lime greatly increased the exchangeable sodium in the lime-phosphate plots (Table XIX) which may be the result of complimentary ion effects--but the depressing effect of phosphate which was also observed is not easy to explain. This depressing effect of phosphate on exchangeable sodium was apparent at all levels of lime.

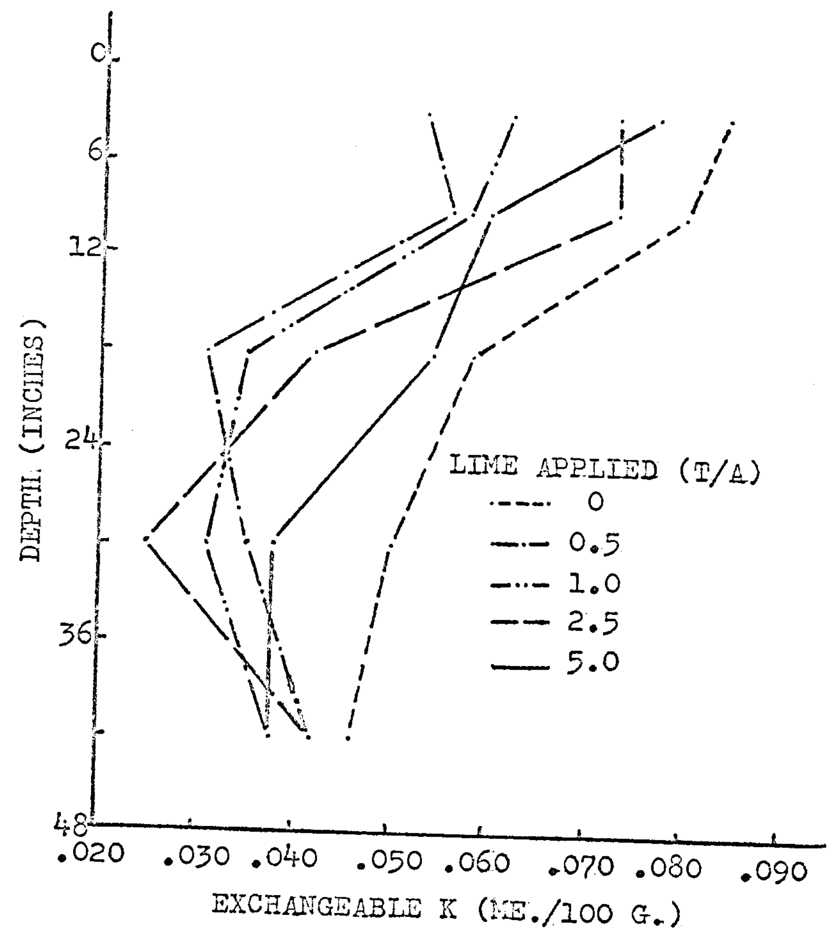

FIGURE 12. INFLUENCE OF LOW-LIME APPLICATIONS ON EXCHANGEABLE K IN AKAKA SOIL PROFILE.

TABLE XVIII. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE Na IN AKAKA SOIL[1]

Silicate carrier	Si applied (T/A)				
	0	0.35	0.70	1.05	1.40
	me/100 g				
TVA slag	0.020	0.034	0.045	0.054	0.057
Volcanic cinders	0.021	0.020	0.027	0.027	0.025

Analysis of Variance

SV	df	MS
Replications	3	0.000035
Treatments	(9)	(0.000780)
Carriers (C)	1	0.003240*
Levels (L)	4	0.000618 n.s.
C x L	4	0.000328**
Error	27	0.000014

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table 16.

TABLE XIX. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE SODIUM IN AKAKA SOIL[1]

P applied	Lime applied (T/A)			
	0	2	9.5	17
(lb/A)	me/100 g			
0	0.027	0.034	0.047	0.047
88	0.024	0.026	0.034	0.047
176	0.022	0.030	0.039	0.044

Analysis of Variance

SV	df	MS
Replications	3	0.00000100
Phosphate (P)	2	0.00011300 n.s.
Lime (L)	3	0.00134000**
P x L	6	0.00002600*
Error	33	0.00000873

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendic Table 19.

Exchangeable sodium in the profiles was little affected by liming (Appendix Tables 10 - 11) since there was very little sodium in the liming materials (Table II). Inasmuch as sodium is continuously removed by crops or leached from this soil, it is presumed that the depletion of sodium is constantly replenished by rain.

Cation exchange capacity. Two ammonium compounds, neutral N ammonium acetate and unbuffered (pH 5.1) N ammonium chloride were compared to find out if an unbuffered system would result in a more realistic value for cation exchange capacity since charge in this soil is likely pH-dependent.

As a general trend cation exchange capacity of surface soils determined by either methods increased with increasing amounts of slag applied. This increase could be due to both pH and silicate effects as stated by Davis (1945) and Onikura (1959). The cation exchange capacity determined by these two extractants are compared in Table XX.

Cation exchange capacity determined by either method decreased with depth in the profile (Figure 13 and Appendix Table 10). The decreasing trend of cation exchange capacity with increasing depth may be due to increasing organic matter content in the profile. That the zero-lime plot showed a somewhat lower cation exchange capacity than the high-lime plot by both methods seems to substantiate the findings of Davis (1945) who stated that liming increased cation exchange capacity. Hydrol Humic Latosols have a higher cation exchange capacities (and organic matter) than other Hawaiian soil groups (Kanehiro and

TABLE XX. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON CATION EXCHANGE CAPACITY OF AKAKA SOIL[1]

Rate (T/A)	NH_4Ac	NH_4Cl
	me/100 g	
0	30.3	28.3
2	29.6	29.2
4	31.4	30.7
6	33.2	32.2
8	32.3	33.2

[1]Replicates were composited; field-moist basis, 40 ± 3% dry matter.

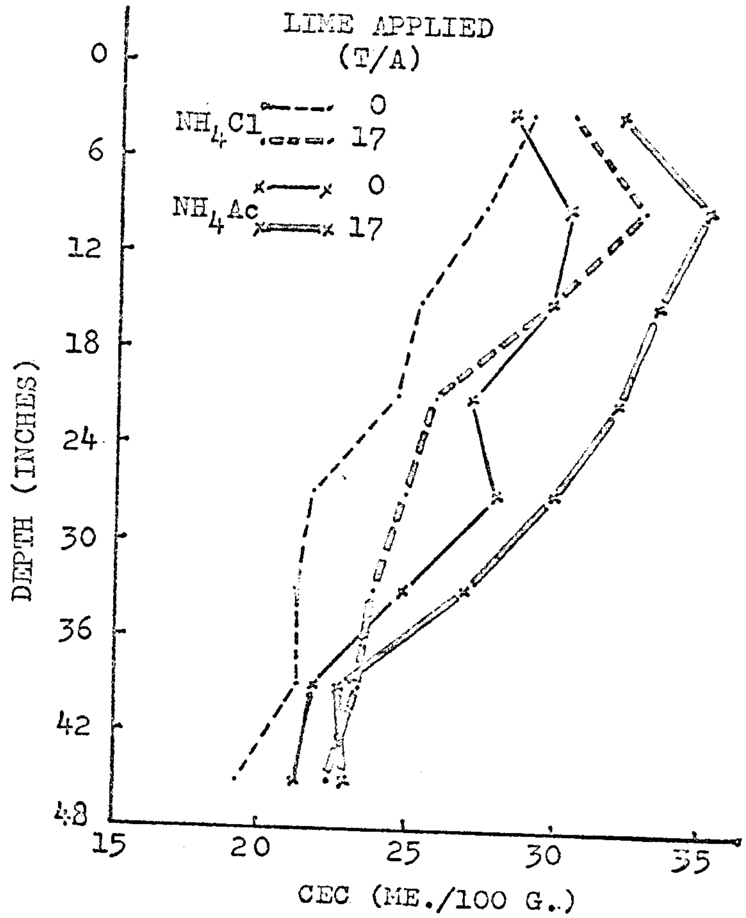

FIGURE 13. EFFECT OF ZERO- AND 17-TON LIME APPLICATION ON CEC OF AKAKA SOIL PROFILE USING N NEUTRAL AMMONIUM ACETATE AND UNBUFFERRED N NEUTRAL AMMONIUM CHLORIDE

Chang, 1956). On an oven-dry basis its cation exchange capacity would range from 50 to 80 me/100 g. However, it is clear from this study that these cation exchange values cannot be interpreted in the conventional manner.

The slightly higher values of cation exchange capacity obtained with ammonium acetate could be due to its buffering effect. The neutral reaction of the system must have precipitated exchangeable iron and aluminum in the acid soils thus increasing the pH-dependent negative charge component and the efficiency of NH_4^+ adsorption. This explanation, however, can hardly be applied to the limed plot.

Extractable silicon. Extractable silicon was increased in plots which received TVA slag but the amount of silicon extracted was not proportional to the quantity of silicon added (Table XXI). Evidently, some of the silicon added combined with aluminum and iron to form silicate compounds of extremely low solubility or perhaps since calcium silicate is a compound having low solubility, it had not yet gone into solution at the time of sampling.

The amount of extractable silicon was mostly influenced by the first and last increments of silicate applied. Whether this is a general effect or caused by something else such as soil variation was not determined.

A small but statistically highly significant increased in extractable silicon resulted from lime applications (Table XXII). The increased in the limed plots may be due to any or all of the four following factors: (1) increasing pH which solubilized more silicon from soil mineral silicates; (2) decrease in number of

TABLE XXI. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON EXTRACTABLE Si IN AKAKA SOIL[1]

Rate	Si
(T/A)	ppm
0	96
2	188
4	237
6	254
8	339

Analysis of Variance

SV	df	MS
Replications	3	180.53333
Levels	4	32230.1750**
Error	12	790.5750

Rp values for Duncan's Test

p		2	3	4	5
Rp:	5%	43.3	45.3	46.5	47.4
	1%	60.8	63.3	65.0	66.3

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table 20.

TABLE XXII. EFFECT OF VARYING AMOUNTS OF LIME ON EXTRACTABLE Si IN AKAKA SOIL[1]

Rate	Si
(T/A)	ppm
0	101
2	109
9.5	114
17	124

Analysis of Variance

SV	df	MS
Replications	3	8.23
Levels	3	394.40**
Error	9	5.67

Rp values for Duncan's Test

p		2	3	4
Rp:	5%	3.84	4.01	4.11
	1%	5.52	5.75	5.89

[1]Values are means of 4 replications, moist basis. For replicates and dry matter content of the soil, see Appendix Table 21.

pH-dependent positive charges with increasing pH; (3) increasing bicarbonate, hydroxide or carbonate for anion exchange; and (4) increased solubility of silicon caused by the extracting solution which contained a high amount of phosphate.

Extractable sulfur. Water-soluble sulfur increased with increasing TVA slag (Table XXIII). This increase can be attributed to increasing pH of the slag plots (Table V) and also to increasing silicate in the slag which could have brought more sulfate into solution by anion exchange.

Potassium dihydrogen phosphate at a concentration of 500 ppm P is evidently a very effective extractant for sulfate compared with water. The amount of sulfur extracted by this reagent was about 40 times more than with water. When phosphate was used as extractant for sulfate the trend (increasing extractable sulfate with increasing rates of slag) is scarcely evident. The large amount of sulfate extracted may have masked solubility effects. The phosphorus solution was also bufferred which could have masked the effect of silicate on soil pH. Likewise, the relatively large amount of phosphate in the extractant would have masked the solubility effect of silicate. It is also possible that silicate does not displace sulfate as efficiently as phosphate.

The increase in water-soluble sulfur with increasing lime (Figure 14 and Appendix Table 22) and phosphate indicates that lime solubilized the adsorbed sulfate in the soil, probably as a result of decreased anion exchange capacity. The phosphate also must have released some sulfur into solution by anion

TABLE XXIII. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON EXTRACTABLE S IN AKAKA SOIL[1]

Rate (T/A)	Water-soluble S	KH_2PO_4-extractable S
	ppm	
0	6.5	242
2	13.6	243
4	28.1	245
6	31.8	269
8	39.0	261

[1]Replicates were composited; field-moist basis, $40 \pm 3\%$ dry matter.

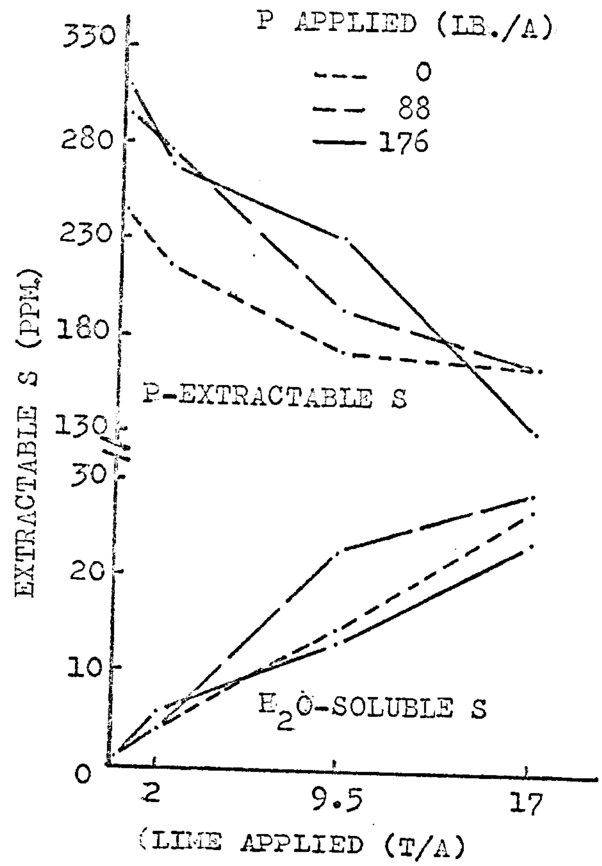

FIGURE 14. EFFECT OF LIME AND PHOSPHATE ON H_2O-SOLUBLE AND P-EXTRACTABLE S FOUR YEARS AFTER APPLICATION ON AKAKA SOIL 1/

exchange. Since this soil has a relatively high amount of organic matter, it is also possible that some of the sulfur in the organic matter had been solubilized.

Decreasing phosphate-extractable sulfur with increasing lime and phosphate suggests that much of the sulfur solubilized by lime moved downward by leaching. Further evidence on this point will be presented later.

Heavy lime applications lead to sulfur depletion unless the sulfur leached from the soil is replenished (Jordan, 1964). Heavy liming may also have an indirect effect on phosphate availability through solubilization of sulfur (which in turn solubilizes phosphate) in soils with high phosphorus-fixing capacity. On the other hand, high concentrations of sulfate in the soil may depress phosphate uptake by plants through ionic antagonism as shown by experiments on potatoes (Gausman, et al 1958).

Phosphorus fertilization increased phosphate-extractable sulfur from the unlimed and moderately limed Akaka soil. When the soil was over-limed, additions of phosphate fertilizer may have depressed sulfate extraction. A possible explanation is the effect of these treatments on the solubility of the phosphate extractant. If so, the "seed-crystal" concept[4] may help explain the low result from high phosphate and lime treatments.

Phosphate-extractable sulfur in the profiles of the zero- and 17-ton lime plots of the lime-phosphate experiment is shown in Figure 15

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[4]R. L. Fox (unpublished) has suggested that precipitates formed as a result of earlier fertilization may provide seed crystals which may hasten the precipitation of phosphorus from later applications.

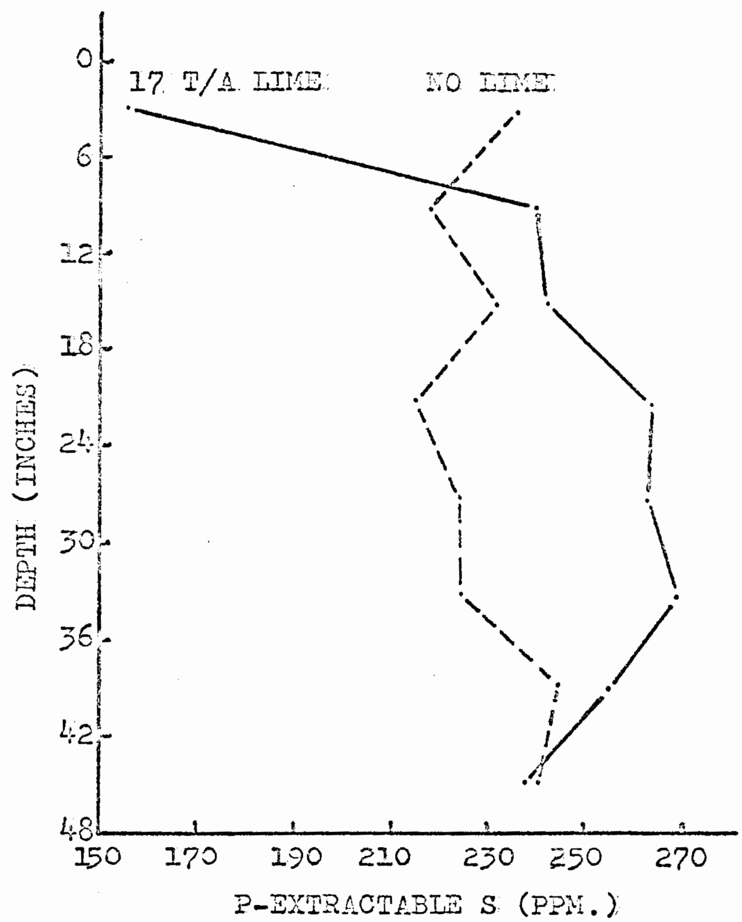

FIGURE 15. EFFECT OF ZERO- AND 17-TON LIME APPLICATION ON P-EXTRACTABLE S IN AKAKA SOIL PROFILE

(Appendix Table 23). Two outstanding features are evident: (1) Extractable sulfur was high throughout the profile. (2) Sulfur in the surface soil was much less in the limed plots. Evidently, sulfate solubilized by lime moved downward and may in part account for sulfate accumulation in the subsoil of the limed plots. This soil is high in R_2O_3 and coatings of iron and aluminum oxides increase adsorption of sulfate by clays (Chao, et al 1964).

Biological Evaluation of Silicate and Lime Application

Pot tests were conducted in the greenhouse, using Sudan and Para grasses as indicators of the effects of field-applied lime and silicate on growth and plant composition. The soils used were from the field plots described as silicate and lime-phosphate experiments in the Materials and Methods section.

Yield. Clements (1965, in press) reported a yield response (partial results) to TVA slag by sugar cane in both tones cane per acre and tons pol per acre (Appendix Table 24). Application of volcanic cinders was accompanied by the lowest cane tonnage but its pol per cent of cane was comparable to that of TVA slag. The mixture of volcanic cinders and coral stone was associated with a relatively much higher cane tonnage than cinders alone but had the lowest pol per cent of cane. There was no different between volcanic cinders applied alone and its mixture with coral stone in tons pol per acre. Evidently, lime, although it increases cane tonnage, tends to reduce pol per cent.

TVA slag increased the yield of Sudan but not of Para grass grown in greenhouse (Table XXIV). The cinders had no effect on the yields of either grass. TVA did seem to have an effect (but not statistically significant) on soluble phosphorus in the soil (Table X). The possibility that the increase in yield of Sudan grass was related to improved phosphate nutrition can not be disregarded. It is more probably that the response was due either to calcium or silicon as will be discussed later. It could also be due to pH effects.

The fact that the yield of Para grass was practically the same in TVA and cinder plots suggests that this grass has a more effective feeding power than Sudan grass or that it is less sensitive to its nutritional environment. The roots of both grasses were examined after harvest and those of Para grass were found better developed than those of Sudan grass.

Yields of Sudan grass were increased by liming. Phosphate had no effect on Sudan grass yield nor was there significant interaction between phosphate and lime. Para grass responded in a similar manner. However, a slightly decreasing trend in yield due to increasing lime in the presence of phosphate is evident although this interaction did not reach the 5% level of significance. The yields of the two grasses in the lime-phosphate experiment are compared in Table XXV.

The depressing effect of phosphate on yield with increasing lime was consistent throughout the replications (Appendix Table 26). This effect of

TABLE XXIV. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON DRY MATTER YIELD OF SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		g/pot				
TVA slag	S. grass	10.65	13.77	14.57	15.60	14.04
	P. grass	14.38	14.45	14.15	15.02	14.72
Volcanic cinders	S. grass	8.83	10.42	10.14	8.86	9.16
	P. grass	14.95	12.49	14.56	14.04	13.55

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	0.0538	2	0.4462
Treatments	(9)	(20.3450)	(9)	(1.6944)
Carriers (C)	1	134.9592**	1	2.9329
Levels (L)	4	7.0152 n.s.	4	1.3268
C x L	4	5.0212**	4	1.7523
Error	18	1.0921	18	1.0602

[1]Values are means of 3 replications. For replicates, see Appendix Table 20.

TABLE XXV. EFFECT OF LIME AND PHOSPHATE ON DRY MATTER YIELD OF SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied (lb/A)	Grass	Lime applied (T/A) 0	2	9.5	17
		g/pot			
0	S. grass	8.67	10.36	12.56	13.51
	P. grass	13.21	15.01	13.74	14.28
88	S. grass	9.58	9.85	13.10	12.50
	P. grass	14.58	13.68	13.37	11.98
176	S. grass	7.69	11.22	11.96	11.98
	P. grass	14.17	14.35	13.77	12.43

Analysis of Variance

SV	S. grass df	MS	P. grass df	MS
Replications	2	1.3864	2	1.8780
Phosphate (P)	2	1.2314	2	1.3572
Lime (L)	3	32.6980**	3	3.6133 n.s.
P x L	6	1.8981	6	2.0387
Error	22	1.2864	22	0.9535

Rp values for Duncan's Test for S. grass

p	2	3	4
Rp: 5%	1.90	2.00	2.07
1%	2.60	2.70	2.78

[1] Values are means of 3 replications. For replicates, see Appendix Table 21).

phosphate was also evident in Sudan grass yields at the highest lime rate. Under high applications of lime and phosphate to acid soils several reactions could occur which would depress availability of nutrients, notably the trace elements. This, in turn, could cause decreases in yields. Zinc solubility for example, could be drastically diminished when phosphate immobilizes it as zinc phosphate and high pH precipitates it out of solution.

Phosphorus uptake. TVA slag and cinders did not significantly affect total phosphorus uptake of either grass (Table XXVI). Para grass had a relatively higher phosphorus uptake than Sudan grass. This may suggest a better developed root system of Para grass.

Lime interacted with phosphate but did not adversely affect total phosphorus uptake by either grass (Figure 16 and Table XXVII). Evidently, the better growth in Sudan grass as a result of liming was associated with higher uptake of both soil and fertilizer phosphorus. Para grass did not show any increase in total phosphorus uptake with increasing lime and phosphate since its growth response was more or less uniform for all treatment levels.

Soil phosphorus uptake. In this study soil and residual fertilizer phosphorus were indistinguishable. For purposes of discussion the term soil phosphorus will be used.

There was practically no effect of either slag or cinders on soil phosphorus uptake by Para grass but in Sudan grass slag did show a statistical significance over the cinders (Table XXVIII).

TABLE XXVI. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON TOTAL P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	9.12	8.62	8.75	9.70	9.48
	P. grass	11.64	13.49	11.34	13.14	13.98
Volcanic cinders	S. grass	10.04	9.33	10.14	9.97	9.83
	P. grass	11.89	12.18	11.91	12.66	12.88

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	0.0871	2	0.0200
Treatments	(9)	(0.8578)	(9)	(2.2188)
Carriers (C)	1	3.9531*	1	1.2896
Levels (L)	4	0.6296	4	3.6636 n.s.
C x L	4	0.3122	4	1.0065
Error	18	1.6263	18	1.2208

[1]Values are means of 3 replications. For replicates see Appendix Table 27.

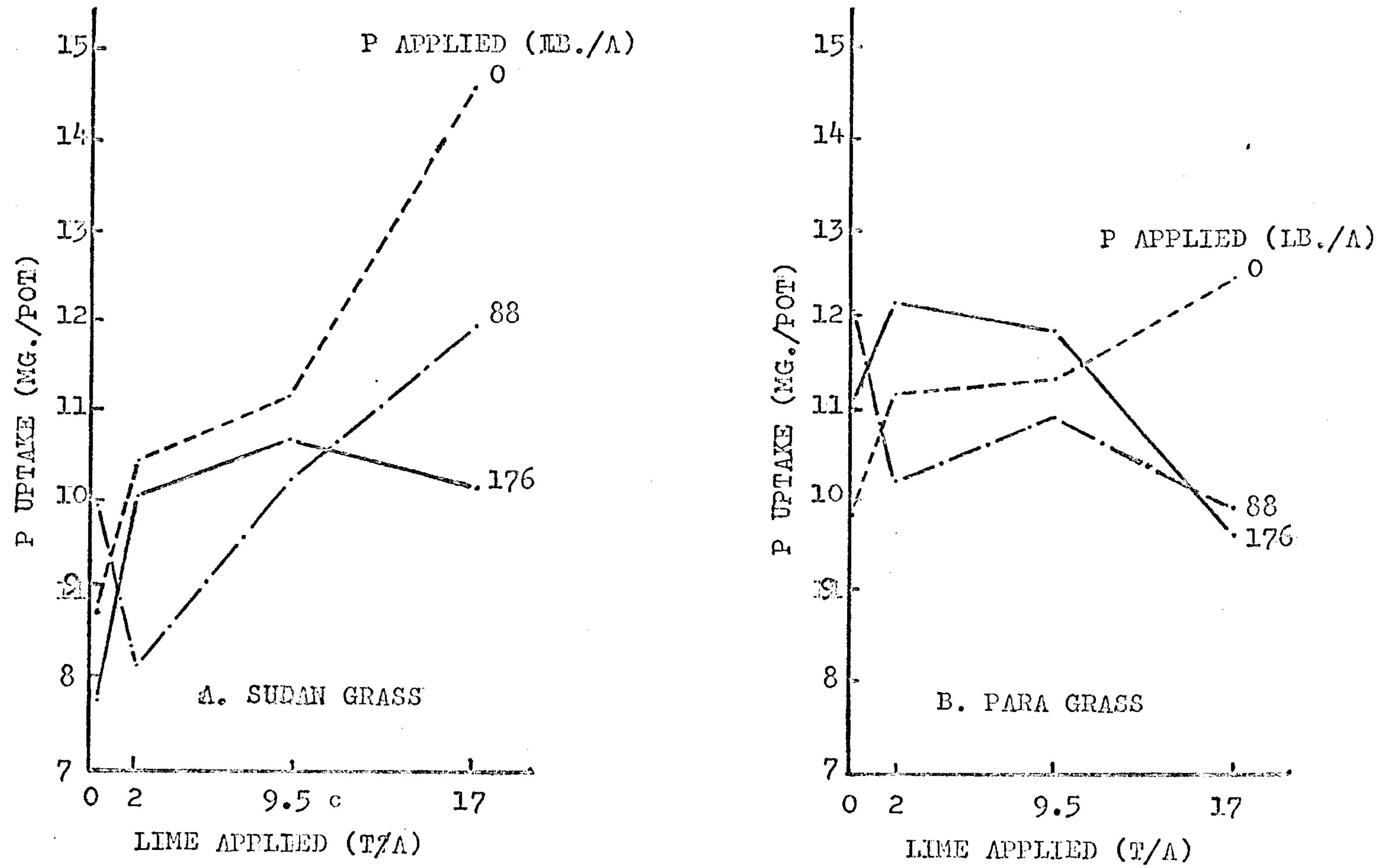

FIGURE 16. EFFECT OF LIME AND PHOSPHATE APPLIED TO AKAKA SOIL IN 1959 ON TOTAL P UPTAKE BY SUDAN AND PARA GRASSES IN 1964

TABLE XXVII. EFFECT OF LIME AND PHOSPHATE ON TOTAL P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied	Grass	Lime applied (T/A)			
		0	2	9.5	17
(lb/A)		mg/pot			
0	S. grass	8.73	10.41	11.18	14.59
	P. grass	9.86	11.19	11.31	12.45
88	S. grass	9.98	8.18	10.26	11.92
	P. grass	12.02	10.22	10.90	9.89
176	S. grass	7.79	10.03	10.68	10.11
	P. grass	11.13	12.18	11.84	9.59

Analysis of Variance

SV	S. grass		P. grass	
	df	MS	df	MS
Replications	2	0.8798	2	1.9416
Phosphate (P)	2	7.9646 n.s.	2	0.7708
Lime (L)	3	19.7277 n.s.	3	0.8409
P x L	6	5.2770**	6	4.5731**
Error	22	0.6762	22	0.9612

[1]Values are means of 3 replications. For replications see Appendix Table 28.

TABLE XXVIII. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON SOIL AND RESIDUAL FERTILIZER P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	1.58	3.17	2.73	1.40	3.33
	P. grass	2.80	4.78	4.13	2.85	5.57
Volcanic cinders	S. grass	3.31	2.55	3.00	3.09	3.50
	P. grass	4.99	5.07	2.97	4.18	4.34

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	1.0936	2	2.3886
Treatments	(9)	(1.5983)	(9)	(2.9747)
Carriers (C)	1	3.1623*	1	0.6021
Levels (L)	4	1.2173	4	3.1104 n.s.
C x L	4	1.5883	4	3.4323*
Error	18	0.5929	18	1.0041

[1]Values are means of 3 replications. For replicates, see Appendix Table 19.

In the lime-phosphate experiment, treatments were associated with greater soil phosphate uptake by Sudan grass (Figure 17 and Table XXIX). Soil phosphorus uptake by Sudan grass also tended to increase with increasing phosphate fertilizer applications but the increase was not statistically significant. Phosphorus in Para grass was not influenced by either lime or phosphate treatments.

Fertilizer phosphorus uptake. Neither of the silicate carriers had a significant influence on the uptake of fertilizer phosphorus by Sudan or Para grass (Table XXX).

The relatively high values for fertilizer phosphorus absorbed by both grasses in the 6-ton level were due to unusually high value in one replicate for Sudan grass and in two replicates for Para grass. This is difficult to explain unless a possibility occurred that there was a duplication in the application of fertilizer phosphorus to those pots.

In the lime-phosphate plots, both grasses had the highest fertilizer phosphorus uptake at the zero-P and 17-ton lime levels and very low uptake of fertilizer phosphorus at the highest rates of phosphate and lime (Figure 17). It seems that the interaction of phosphate with lime had a depressing effect on yield of both grasses. The uptake of fertilizer phosphorus by both grasses in the lime-phosphate experiment is shown in Table XXXI.

Phosphorus A-value. Neither silicate carriers had significant effects on phosphorus A-value for either grass. As expected, Para grass gave higher

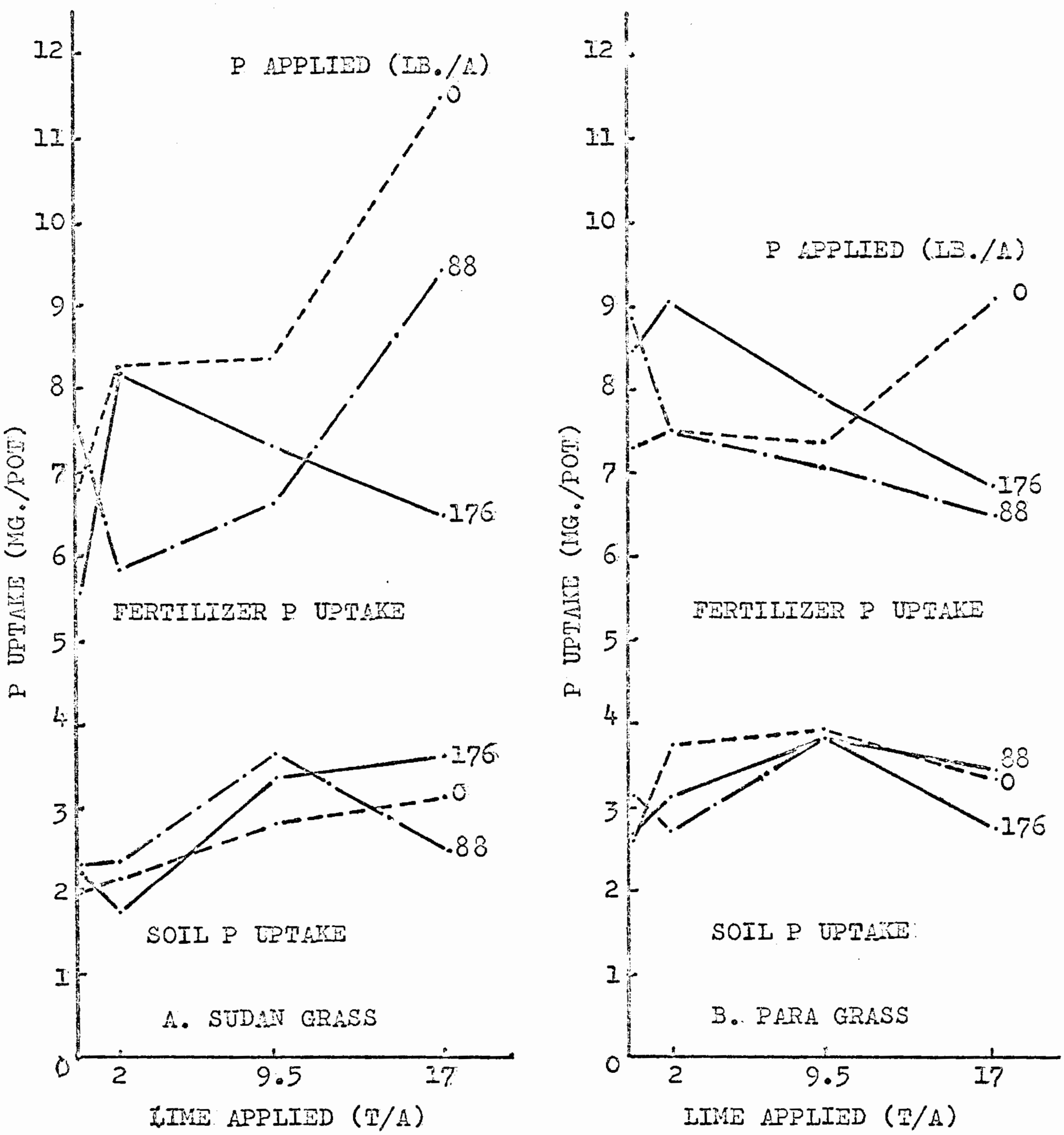

FIGURE 17. EFFECT OF LIME AND PHOSPHATE APPLIED TO AKAKA SOIL IN 1959 ON SOIL AND FERTILIZER P UPTAKE BY SUDAN AND PARA GRASSES IN 1964

TABLE XXIX. EFFECT OF LIME AND PHOSPHATE ON SOIL AND RESIDUAL FERTILIZER P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied	Gras	Lime applied (T/A)			
		0	2	9.5	17
(lb/A)		mg/pot			
0	S. grass	1.93	2.17	2.81	3.13
	P. grass	2.56	3.71	3.94	3.38
88	S. grass	2.33	2.35	3.63	2.47
	P. grass	3.18	2.71	3.83	3.39
176	S. grass	2.26	1.73	3.38	3.64
	P. grass	2.69	3.12	3.93	2.76

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	0.3208	2	0.5432
Phosphate (P)	2	0.1994	2	0.2250
Lime (L)	3	3.3598	3	1.8855 n.s.
P x L	6	0.6022	6	0.4181
Error	22	0.6984	22	0.7818

[1]Values are means of 3 replications. For replicates, see Appendix Table 30.

TABLE XXX. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON FERTILIZER P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	7.54	5.45	6.02	8.30	6.15
	P. grass	8.84	8.71	7.21	10.29	8.41
Volcanic cinders	S. grass	6.72	6.78	7.13	6.88	6.32
	P. grass	6.90	7.11	8.94	8.54	

Analysis of Variance

SV	S. grass df	MS	P. grass df	MS
Replications	2	1.2776	2	1.9766
Treatments	(9)	(1.9809)	(9)	(3.1606)
Carriers (C)	1	0.0441	1	3.6540
Levels (L)	4	2.3057	4	2.3776
C x L	4	2.1404	4	3.8282
Error	18	1.2825	18	1.4901

[1]Values are means of 3 replications. For replicates, see Appendix Table 31.

TABLE XXXI. EFFECT OF LIME AND PHOSPHATE ON FERTILIZER P UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied	Grass	Lime applied (T/A)			
		0	2	9.5	17
(lb/A)		mg/pot			
0	S. grass	6.80	8.27	8.35	11.46
	P. grass	7.30	7.48	7.37	9.07
88	S. grass	7.64	5.82	6.63	9.45
	P. grass	8.84	7.51	7.07	6.50
176	S. grass	5.53	8.30	7.30	6.46
	P. grass	8.44	9.06	7.91	6.83

Analysis of Variance

SV	S. grass		P. grass	
	df	MS	df	MS
Replications	2	0.2432	2	0.4336
Phosphate (P)	2	10.6617 n.s.	2	8.7902**
Lime (L)	3	9.7107 n.s.	3	6.4806**
P x L	6	6.6588**	6	0.6651
Error	22	0.6362	22	0.6956

[1]Values are means of 3 replications. For replicates, see Appendix Table 32.

phosphorus A-values than Sudan grass, indicating its higher phosphate-absorbing power. A comparison of the A-values for both grasses in the silicate treated pots is in Table XXXII.

Earlier experiments in Hawaiian soils with high phosphate fixing capacity showed sugar cane response to phosphorus up to 12 months old after which it leveled off and totally disappeared at harvest (Clements, 1962). This is evidence that sugar cane, having a well developed root system, could absorb phosphorus from the phosphorus reserve in this soil. This reserve may be composed of both organic and inorganic phosphorus since Akaka soil has a relatively high organic matter content (15-20%).

Neither phosphate nor lime affected significantly the phosphorus A-values for either grass (Figure 18 and Table XXXIII). "A" value is a measure of the amount of P which has equilibrated with added P. This is not to say that it is soluble or extractable at any given instant but it should give an indication of the "pool" from which the plant can draw.

The relatively high phosphorus A-value for this soil reveals some peculiar nature of its phosphate fixation. Extractable phosphorus (Table XI) averaged 4 ppm while plant-available phosphorus (A-value) averaged 35 ppm (Table XXXIII), or about 9 times as much as extractable phosphorus. This ratio also held true in the slag and cinder plots (Tables X and XXXII). What this probably means is that although phosphate is highly fixed in this soil, the removal of small amounts of phosphate from the soil solution by plants causes

TABLE XXXII. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON PHOSPHORUS A-VALUE FOR SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A)				
		0	0.35	0.70	1.05	1.40
		ppm				
TVA slag	S. grass	21.2	51.6	48.2	17.5	54.7
	P. grass	32.7	55.5	59.5	28.7	69.0
Volcanic cinders	S. grass	49.5	37.7	43.7	44.7	55.5
	P. grass	75.0	76.3	34.0	51.1	50.7

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	273.73	2	726.12
Treatments	(9)	(529.11)	(9)	(908.94)
Carriers (C)	1	430.17	1	441.60
Levels (L)	4	533.63	4	706.12
C x L	4	549.32*	4	1228.59*
Error	18	185.08	18	391.38

[1]Values are means of 3 replications. For replicates, see Appendix Table 33.

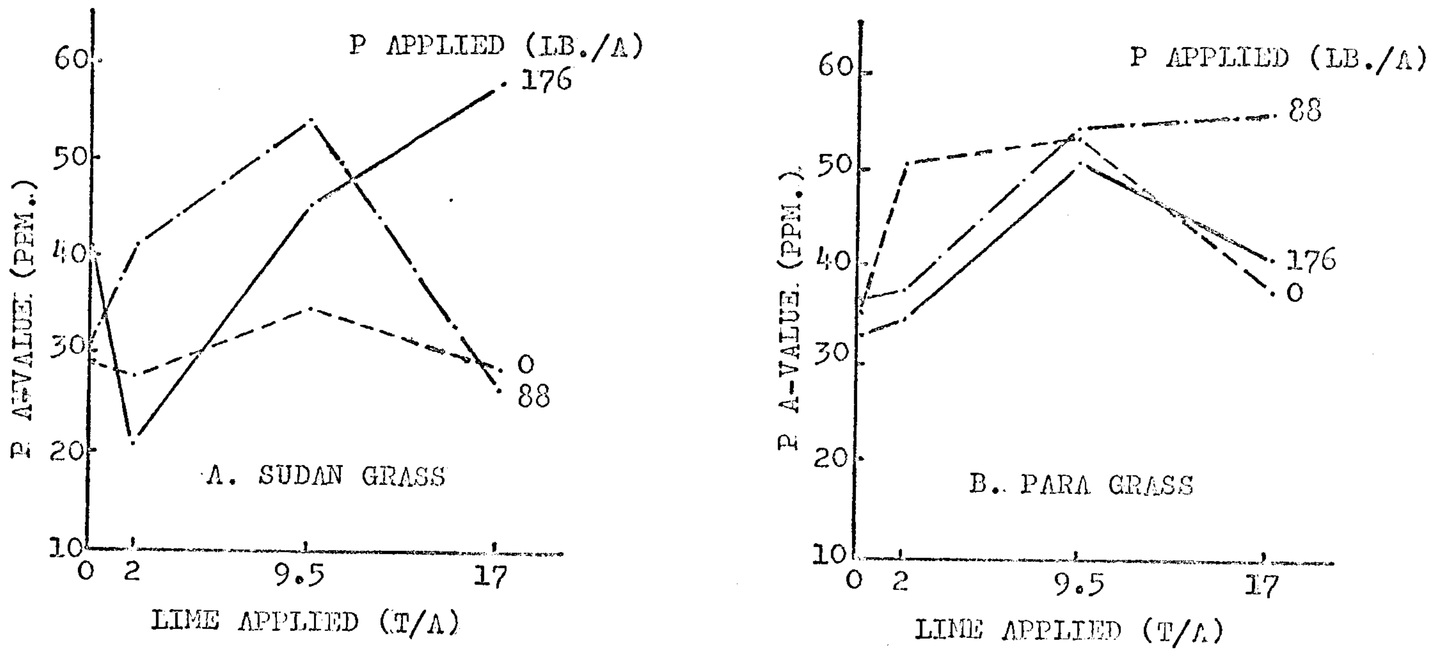

FIGURE 18. EFFECT OF LIME AND PHOSPHATE APPLIED TO AKAKA SOIL IN 1959 ON P A-VALUE OF SUDAN AND PARA GRASS GROWN IN 1964

TABLE XXXIII. EFFECT OF LIME AND PHOSPHATE ON PHOSPHORUS A-VALUE OF SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied	Grass	Lime applied (T/A)			
		0	2	9.5	17
(lb/A)		ppm			
0	S. grass	28.6	27.5	34.9	28.1
	P. grass	35.3	50.3	53.1	37.2
88	S. grass	30.7	41.1	54.6	26.1
	P. grass	36.9	37.5	54.0	55.3
176	S. grass	40.9	20.8	46.6	58.2
	P. grass	32.6	34.4	50.3	40.6

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	139.30	2	95.70
Phosphate (P)	2	444.10 n.s.	2	131.68
Lime (L)	3	403.72 n.s.	3	484.83 n.s.
P x L	6	424.35 n.s.	6	127.91
Error	22	168.91	22	237.43

[1]Values are means of 3 replications. For replicates, see Appendix Table 34.

a rapid shift in the equilibrium of phosphorus from the unavailable to the available form as stated by Pierre and Pohlamn (1933).

Considering the proportion of soil phosphorus to that derived from the fertilizer added, it is highly possible that if both grasses were to rely on soil phosphorus alone, their phosphorus requirement would not be met.

Calcium uptake. TVA slag increased calcium uptake by both Sudan and Para grasses (Table XXXIV). For Para grass rates of slag above 2 tons had little further effect on calcium uptake. There was almost perfect linear correlation between dry matter yield and calcium composition of Sudan grass as a consequence of increasing slag applications (Figure 19)--suggesting that increased calcium uptake may have increased growth. Sudan grass probably has a higher calcium requirement than Para grass which seems to thrive in low-calcium environments. This soil, low in calcium, favored Sudan grass growth with increased rates of calcium in the TVA slag.

In the lime-phosphate experiment, calcium uptake by Sudan grass was depressed at the first increment of lime and phosphate (Figure 20 and Table XXXV). This depressing effect of lime and phosphate on calcium uptake by Sudan grass is apparent at the 9.5-ton lime level (Figure 20A). There is some evidence that the calcium requirement of Sudan grass is met at the 9.5-ton lime level. This is shown by the pattern of calcium uptake at the zero- and 88-lb/A phosphate rates.

TABLE XXXIV. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON CALCIUM UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	26.36	48.71	54.79	60.75	59.35
	P. grass	23.06	29.36	29.21	30.89	32.09
Volcanic cinders	S. grass	24.72	25.26	28.64	25.09	26.37
	P. grass	28.77	21.89	24.15	25.30	24.67

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	4.038	2	1.068
Treatments	(9)	(744.464)	(9)	(37.573)
Carriers (C)	1	4310.166*	1	118.048*
Levels (L)	4	326.884 n.s.	4	9.384
C x L	4	270.619**	4	45.633**
Error	18	12.364	18	4.850

[1]Values are means of 3 replications. For replicates, see Appendix Table 35.

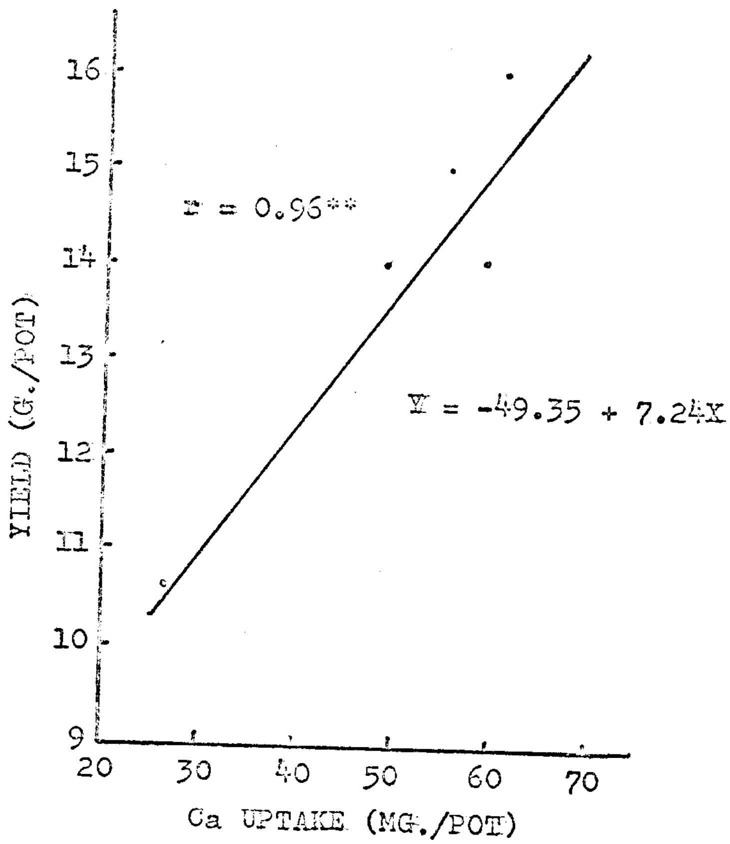

FIGURE 19. RELATIONSHIP BETWEN Ca UPTAKE AND DRY MATTER YIELD OF SUDAN GRASS GROWN ON AKAKA SOIL TREATED WITH TVA SLAG ONE YEAR BEFORE

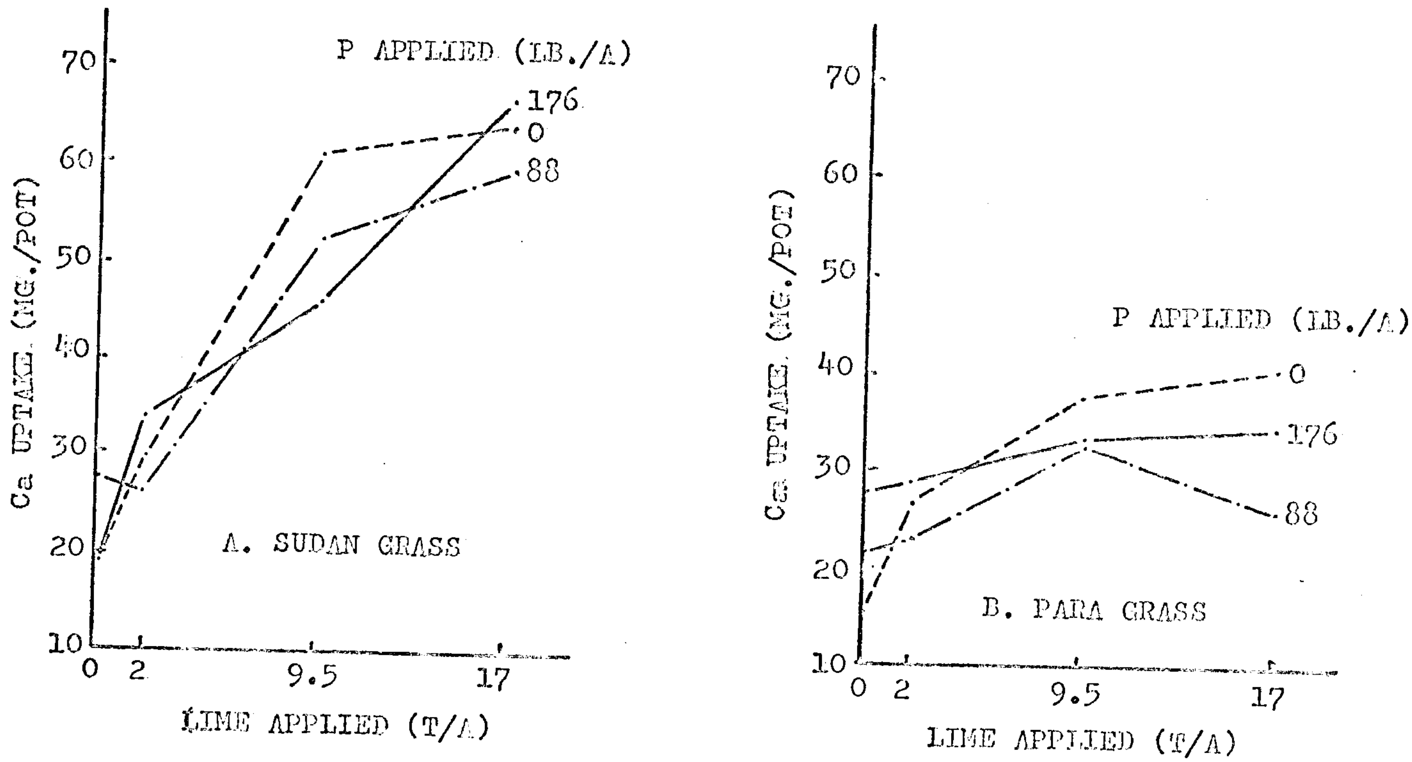

FIGURE 20. EFFECT OF LIME AND PHOSPHATE APPLIED TO AKAKA SOIL IN 1959 ON Ca UPTAKE BY SUDAN AND PARA GRASSES IN 1964

TABLE XXXV. EFFECT OF LIME AND PHOSPHATE ON Ca UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied (lb/A)	Grass	Lime applied (T/A) 0	2	9.5	17
		mg/pot			
0	S. grass	19.38	29.93	60.91	63.95
	P. grass	16.26	26.34	37.45	40.58
88	S. grass	27.03	26.36	52.22	59.87
	P. grass	21.49	22.74	32.05	25.64
176	S. grass	19.44	33.98	35.62	66.76
	P. grass	27.85	28.25	33.05	34.36

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	0.672	2	15.816
Phosphate (P)	2	18.174 n.s.	2	102.988 n.s.
Lime (L)	3	3378.893**	3	325.613 n.s.
P x L	6	98.573**	6	71.688**
Error	22	13.155	22	3.531

[1]Values are means of 3 replications. For replicates, see Appendix Table 36.

Sudan grass took up more calcium than Para grass. This grass seems to have a relatively higher calcium need. The comparative amounts of calcium uptake by the two grasses are shown in Figure 20 and Table XXXV.

Para grass obtained increasing amounts of calcium with increasing phosphate from the unlimed soil (Figure 20B). A negative effect of phosphate on calcium uptake by Para grass was suggested at the highest lime rate.

Aluminum uptake. No definite pattern for aluminum uptake was shown by either grass in either the silicate or the lime-phosphate experiments (Appendix Table 32). This probably indicates that Sudan and Para grasses are facultative as far as aluminum absorption and utilization are concerned. Fox, et al (1964, in press) obtained decreasing aluminum uptake by these grasses with increasing pH that accompanied increasing rates of $Ca(OH)_2$ applications to latosols.

Magnesium uptake. No significant effects resulted from applications of either TVA slag of volcanic cinders on Magnesium uptake by Sudan and Para grasses (Table XXXVI). However, lime applied at 9.5 and 17 tons substantially depressed magnesium uptake by Para grass. This is shown in Table XXXVII. The trend was evident for all phosphorus levels. Probably, increased calcium in the soil associated with liming depressed magnesium uptake through a competitive effect. It is interesting to note that this same effect was observed when calcium was applied as slag (Table XXXVI). Evidently, pot variations were such that the statistics indicate non-significance.

TABLE XXXVI. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON MAGNESIUM UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	30.74	28.20	26.19	27.80	24.47
	P. grass	38.36	32.69	29.38	28.65	27.89
Volcanic cinders	S. grass	26.47	30.24	29.06	26.51	28.48
	P. grass	37.97	35.18	35.42	36.27	38.28

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	1.9588	2	4.2312
Treatments	(9)	(10.9426)	(9)	(50.1932)
Carriers (C)	1	2.6820	1	204.9899 n.s.
Levels (L)	4	7.2062	4	34.6553 n.s.
C x L	4	16.7442	4	37.0343**
Error	18	7.0272	18	4.7433

[1]Values are means of 3 replications. For replicates, see Appendix Table 39.

TABLE XXXVII. EFFECT OF LIME AND PHOSPHATE ON Mg UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied (lb/A)	Grass	Lime applied (T/A) 0	2	9.5	17
		mg/pot			
0	S. grass	28.72	33.79	26.24	24.58
	P. grass	33.07	33.52	22.24	25.51
88	S. grass	30.77	27.85	32.33	29.36
	P. grass	27.91	28.76	26.10	25.62
176	S. grass	23.01	31.48	26.63	27.42
	P. grass	37.37	33.80	29.63	22.48

Analysis of Variance

SV	S. grass df	MS	P. grass df	MS
Replications	2	15.1681	2	17.8106
Phosphate (P)	2	26.2940 n.s.	2	13.5579
Lime (L)	3	28.0945 n.s.	3	260.0072*
P x L	6	33.7694 n.s.	6	27.3363*
Error	22	14.7152	22	7.3335

[1]Values are means of 3 replications. For replicates, see Appendix Table 40.

Nevertheless, the trend is there for both Para and Sudan grasses.

Potassium uptake. TVA slag produced a statistically highly significant effect on potassium uptake by Sudan grass and a significant effect in Para grass (Table XXXVIII). Increasing uptake of potassium with increasing slag may be attributed to better root proliferation and favorable effects of calcium on cytoplasmic membrane in roots.

Volcanic cinders tended to increase potassium uptake by Para grass but not by Sudan grass. Indications are that (1) Para grass is able to weather out non-exchangeable potassium from the cinders and (2) the root is better able than soil to weather cinders since applications of cinders seems to have had no effect on soil potassium. Fox and Kacar (1965) found that legumes were more effective than grass in weathering non-exchangeable potassium in the soil. Thus there is evidence that plants do differ in their ability to weather minerals.

Lime increased potassium uptake by Sudan grass at the 5% level of significance but had no significant effect on Para grass. This seems to be an indication that Sudan grass is more sensitive to potassium supply. A significant interaction between lime and phosphate resulted in depressing potassium uptake by Para grass with increasing lime and phosphate. Potassium uptake by both grasses is shown in Table XXXIX.

Sodium uptake. Slag treatments increased sodium uptake (Table XL). Even the cinder treatments produced a small trend when Para grass was the indicator plant. This could be due to weathering action of Para grass roots on

TABLE XXXVIII. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON K UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	198	226	225	235	236
	P. grass	211	227	237	248	241
Volcanic cinders	S. grass	190	203	209	179	197
	P. grass	205	229	236	230	236

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	38.034	2	206.033
Treatments	(9)	(1158.282)	(9)	(531.722)
Carriers (C)	1	6049.200**	1	252.300
Levels (L)	4	556.217 n.s.	4	1046.917*
C x L	4	237.617 n.s.	4	8.638
Error	18	368.816	18	235.367

[1]Values are means of 3 replications. For replicates, see Appendix Table 41.

TABLE XXXIX. EFFECT OF LIME AND PHOSPHATE ON K UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

P applied	Grass	Lime applied (T/A)			
		0	2	9.5	17
(lb/A)		mg/pot			
0	S. grass	208	227	237	251
	P. grass	239	288	273	289
88	S. grass	221	227	274	238
	P. grass	267	275	209	250
176	S. grass	208	216	252	254
	P. grass	245	264	274	205

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	160.194	2	687.694
Phosphate (P)	2	276.861	2	1877.444 n.s.
Lime (L)	3	3583.706*	3	1838.769 n.s.
P x L	6	414.639 n.s.	6	1513.852*
Error	22	223.649	22	415.895

[1]Values are means of 3 replications. For replications, see Appendix Table 42.

TABLE XL. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON Na UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Silicate carrier	Grass	Si applied (T/A) 0	0.35	0.70	1.05	1.40
		mg/pot				
TVA slag	S. grass	2.70	3.36	3.81	4.07	4.29
	P. grass	10.02	12.71	16.22	22.34	22.01
Volcanic cinders	S. grass	2.20	2.08	2.39	2.04	2.25
	P. grass	10.82	9.94	11.87	12.79	12.82

Analysis of Variance

	S. grass		P. grass	
SV	df	MS	df	MS
Replications	2	0.6807	2	1.7859
Treatments	(9)	(2.3193)	(9)	(63.2594)
Carriers (C)	1	15.8123**	1	188.2507**
Levels (1)	4	0.6565	4	66.2860
C x L	4	0.6088	4	6.4411
Error	18	0.4636	18	3.7272

[1]Values are means of 3 replications. For replications, see Appendix Table 43.

sodium similar to that reported by Fox and Kacar (1965). Para grass took up more sodium than did Sudan grass which may indicate some salt tolerance of the former. In Hawaii Para grass grows in profusion in some swampy areas near the sea which seems to bear out the contention that at least it may tolerate sodium.

Generally, the highest sodium uptake by Sudan and Para grass were obtained from the highest lime and phosphate treatments (Table XLI). This seems to indicate that improved growth with increasing lime increased uptake of sodium by both grasses.

Silicon uptake. Increasing slag increased silicon uptake by both grasses. This is presented in Figure 21 and Table XLII. Silicon though not listed as an essential element to date, was absorbed by these grasses in increasing amounts according to the quantity added to the soil. Significant correlation existed between dry matter yield of Sudan grass and silicon uptake (Figure 22) and between extractable silison in the soil and silicon uptake by Sudan grass (Figure 23).

Lime did not have any effect on silicon uptake by either grass (Table XLIII). Presumably, lime has no solubilizing effect on silicon in the soil or Akaka soil has a very low silica content in a form not readily soluble by dilute acid. This indicates further that the effect of lime on extractable silicon (Table XXII) with phosphate was related to improved efficienty of the phosphate extractant because phosphate remained in solution better in the limed plots.

TABLE XLI. EFFECT OF LIME AND PHOSPHATE ON Na UPTAKE BY SUDAN AND PARA GRASSES ON AKAKA SOIL[1]

P applied (lb/A)	Grass	Lime applied (T/A) 0	2	9.5	17
		mg/pot			
0	S. grass	1.97	1.78	1.74	2.42
	P. grass	11.16	15.34	15.63	16.76
88	S. grass	2.32	3.63	4.73	2.08
	P. grass	12.65	13.90	12.12	13.34
176	S. grass	1.79	2.02	3.60	2.45
	P. grass	11.11	12.73	12.34	10.07

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	0.0898	2	6.9108
Phosphate (P)	2	4.4604 n.s.	2	30.0218 n.s.
Lime (L)	3	2.9539 n.s.	3	9.2423 n.s.
P x L	6	2.9539 n.s.	6	7.5262 n.s.
Error	22	0.8037	22	3.6388

[1]Values are means of 3 replications. For replicates, see Appendix Table 44.

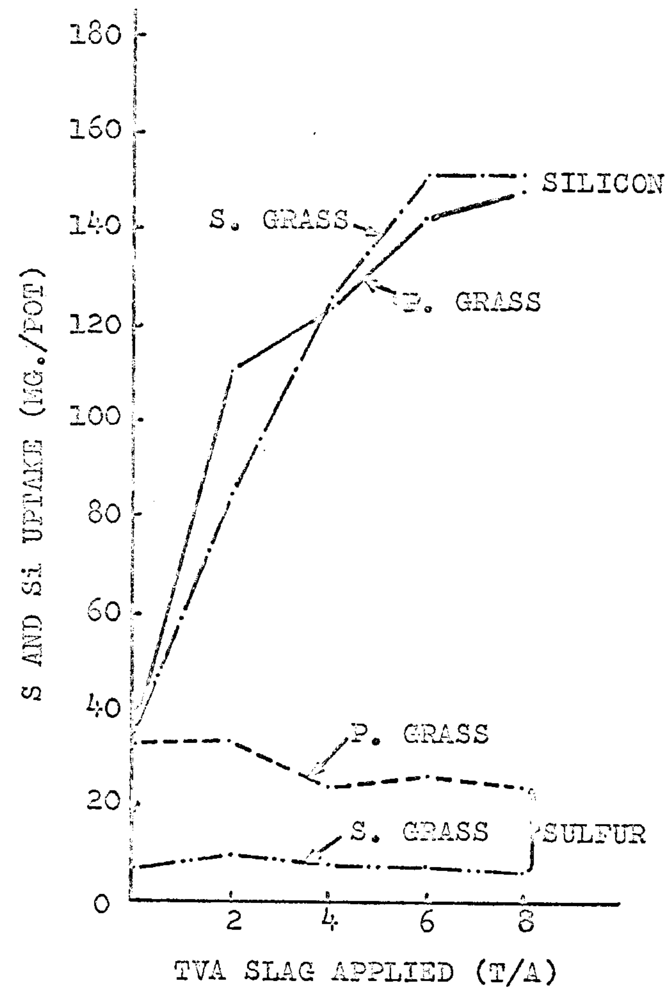

FIGURE 21. INFLUENCE OF TVA SLAG APPLIED TO AKAKA SOIL IN 1963 ON S AND Si UPTAKE BY SUDAN AND PARA GRASSES IN 1964

TABLE XLII. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON Si UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Grass	TVA slag applied (T/A) 0	2	4	6	8
	mg/pot				
S. grass	35	84	126	151	151
P. grass	35	110	124	142	148

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	56.2666	2	91.9667
Levels	4	7550.7666**	4	6209.9000**
Error	8	40.5167	8	71.6750

[1]Values are means of 3 replications, For replicates, see Appendix Table 45.

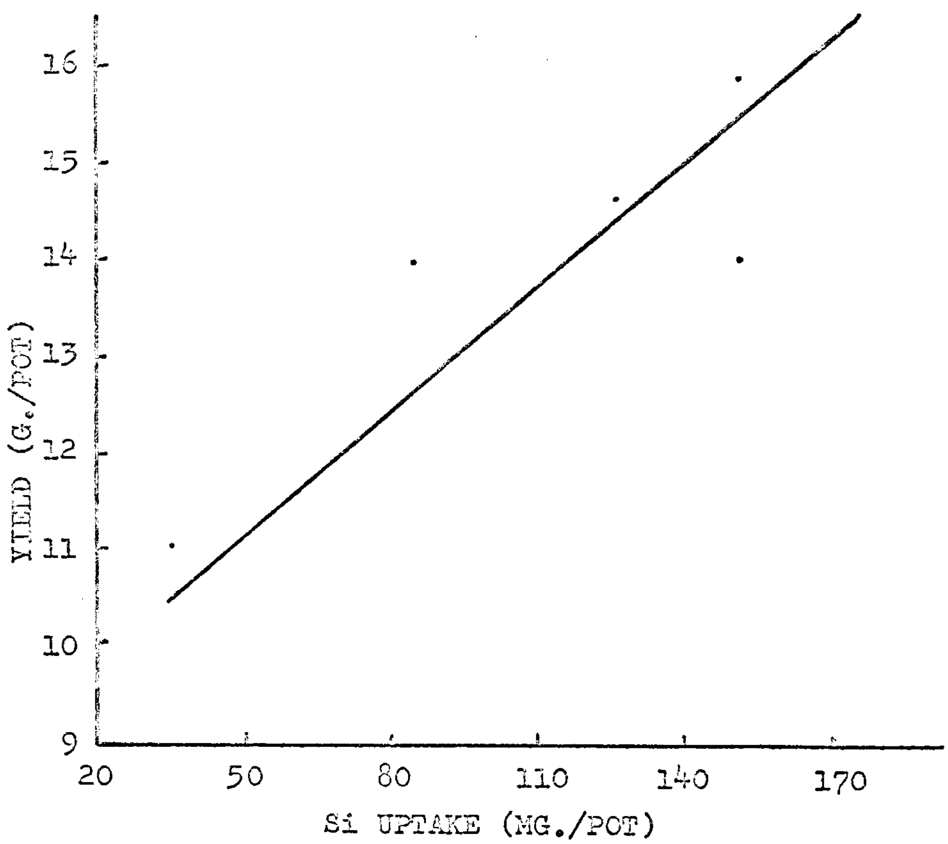

FIGURE 22. RELATIONSHIP BETWEEN Si UPTAKE AND DRY MATTER YIELD OF SUDAN GRASS GROWN IN POTS WITH AKAKA SOIL TREATED WITH TVA SLAG ONE YEAR BEFORE

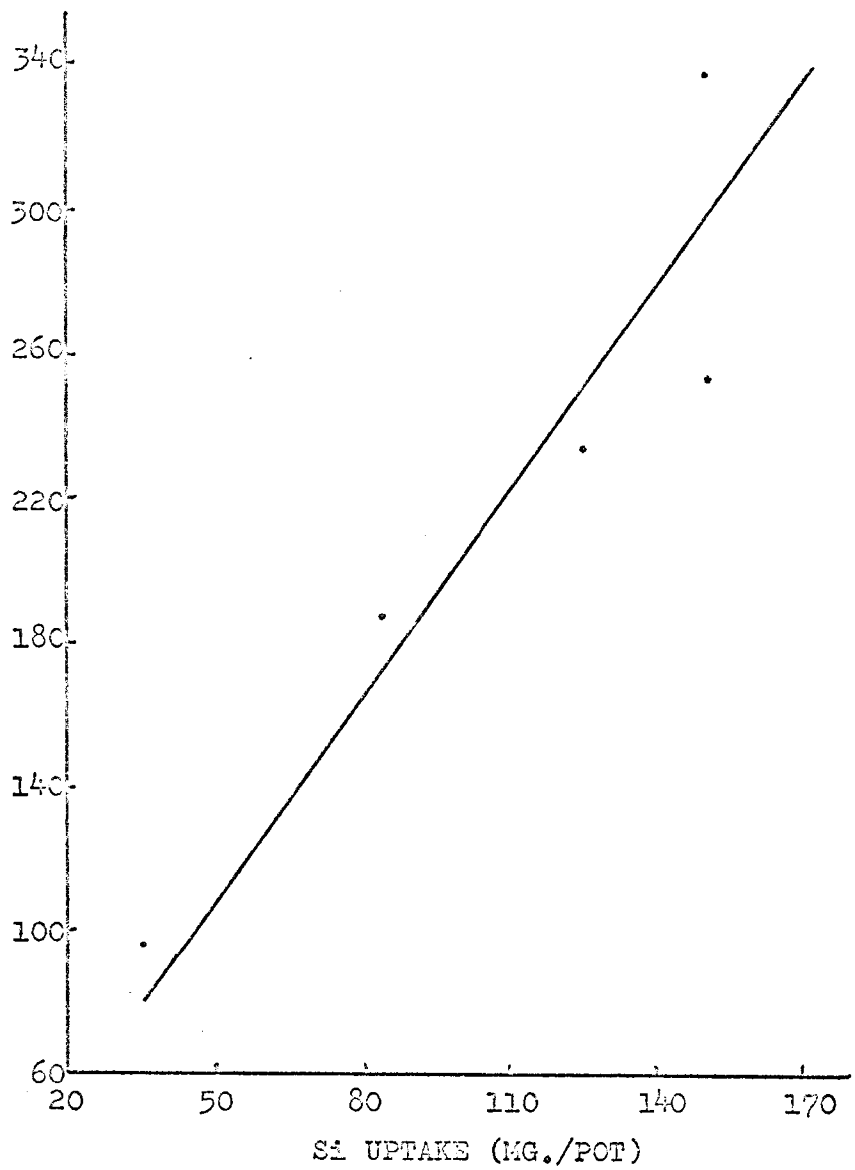

FIGURE 23. RELATIONSHIP BETWEEN Si UPTAKE BY SUDAN GRASS AND EXTRACTABLE Si IN AKAKA SOIL. SOILS HAD BEEN VARIOUSLY TREATED WITH TVA SLAG ONE YEAR BEFORE

TABLE XLIII. EFFECT OF VARYING AMOUNTS OF LIME ON Si UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Grass	Lime applied (T/A)			
	0	2	9.5	17
	mg/pot			
S. grass	35	37	35	38
P. grass	34	37	35	35

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	18.0834**	2	9.25*
Levels	3	6.5556**	3	5.64 n.s.
Error	6	0.9722	6	1.47

[1]Values are means of 3 replications. For replicates, see Appendix Table 46.

Sulfur uptake. Significant decrease in sulfur uptake by both grasses resulted from TVA slag applications (Figure 21). About three times as much sulfur was absorbed by Para grass as by Sudan grass. This may be an indication of a relatively higher sulfur requirement of Para grass. Effects of slag on S uptake is shown in Table XLIV.

Lime significantly increased sulfur uptake by Sudan, but not by Para grass (Table XLV). As in the slag plots Para grass absorbed about 3 times as much sulfur as did the Sudan grass.

Clements (1965, in press) obtained decreasing sulfur uptake by sugar cane (Appendix Table 48) as a result of slag treatments. What these data probably indicate is competitive ion absorption between these two anions.

Summary of Levels of Statistical Significance of Treatment Effects

The levels of statistical significance of the treatment effects on pH and mineral nutrient status in the soil are presented in Table XLVI. In Table XLVII are shown the statistical significance of the treatment effects on nutrient uptake by Sudan and Para grasses grown on Akaka soil.

TABLE XLIV. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON S UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Grass	TVA slag applied (T/A)				
	0	2	4	6	8
	mg/pot				
S. grass	7.52	8.86	6.77	6.78	6.46
P. grass	32.87	32.59	24.25	26.37	24.50

Analysis of Variance

SV	S. grass		P. grass	
	df	MS	df	MS
Replications	2	0.5044	2	1.8654
Levels	4	2.7983*	4	55.2804**
Error	8	0.4354	8	3.8681

[1]Values are means of 3 replications. For replicates, see Appendix Table 47.

TABLE XLV. EFFECT OF VARYING AMOUNTS OF LIME ON S UPTAKE BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL[1]

Grass	Lime applied (T/A) 0	2	9.5	17
	mg/pot			
S. grass	7.17	7.89	8.11	10.42
P. grass	31.13	28.83	31.98	30.15

Analysis of Variance

SV	S. grass df	S. grass MS	P. grass df	P. grass MS
Replications	2	0.5760	2	0.8454
Levels	3	5.7259*	3	5.4886 n.s.
Error	6	0.8659	6	3.1542

[1]Values are means of 3 replications. For replicates, see Appendix Table 49.

TABLE XLVI. STATISTICAL SIGNIFICANCE OF EFFECT OF SILICATE, LIME AND PHOSPHATE MATERIALS ON P FIXATION, pH, EXCHANGEABLE BASES AND EXTRACTABLE P AND Si IN SURFACE SOIL OF AKAKA SERIES

Treatment	pH	Fertilizer remaining in solution	Exchangeable				Extractable	
			Ca	Mg	K	Na	P	Si
TVA slag	*	*	*	n.s.	n.s.	*	n.s.	**
Volcanic cinders	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Volcanic cinders + coral stone	*	n.s.	--	--	--	--	--	--
Lime	**	--	**	**	**	**	n.s.	**
Phosphate	**	--	n.s.	n.s.	n.s.	n.s.	n.s.	--
Lime x phosphate	**	--	*	**	**	*	**	--

*Significant at the 5% level
**Significant at the 1% level
n.s. Not significant

TABLE XLVII. STATISTICAL SIGNIFICANCE OF EFFECTS OF SILICATE, LIME AND PHOSPHATE MATERIALS ON YIELD AND NUTRIENT OF SUDAN AND PARA GRASSES GROWN IN POTS ON AKAKA SOIL

Treatment	Yield	Ca	Mg	K	Na	Soil P	Fert. P	Total P	P A-value	S	Si
					Sudan grass						
TVA slag	**	*	n.s.	**	**	*	n.s.	*	n.s.	n.s.	**
Volcanic cinders	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	--	--
Lime	**	**	n.s.	*	n.s.	n.s.	**	**	n.s.	*	**
Phosphate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	**	n.s.	--	--
Lime x Phosphate	n.s.	**	n.s.	n.s.	n.s.	n.s.	**	**	n.s.	--	--
					Para grass						
TVA slag	n.s.	*	n.s.	n.s.	--	n.s.	n.s.	n.s.	n.s.	**	**
Volcanic cinders	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	--	--
Lime	n.s.	n.s.	*	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.
Phosphate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	--	--
Lime x Phosphate	n.s.	**	*	*	n.s.	n.s.	n.s.	**	n.s.	--	--

*Significant at the 5% level
**Significant at the 1% level
n.s. Not significant

SUMMARY AND CONCLUSION

Calcium silicate (slag) applications increased soil pH, cation exchange capacity, exchangeable bases and extractable sulfur and silicon. It decreased phosphate fixation and slightly increased extractable phosphorus. In contrast, volcanic cinders did not have any noticeable effect on any of the foregoing except exchangeable sodium which showed an increasing trend with increasing levels of cinders.

Liming increased pH, cation exchange capacity and exchangeable bases. It increased extractable sulfur but not extractable silicon. It decreased extractable soil phosphorus but may increase the extractability of fertilizer phosphorus. Phosphate added with lime had very little effect on pH and exchangeable bases. It increased extractable silicon and sulfur.

After 7 years, the effect of coral stone, applied at the rate of 5 T/A was small but measurable in that soil pH was higher down to a depth of 4 feet in the profile of Akaka soil. It is evident that calcium leached quite readily even though cation exchange capacity is high. The effect of high rates of lime on pH were very much evident 4 years after application. The lime requirement of the soil seems to be about 10 tons per acre of coral stone. Lime applied at about the lime requirement or greater, increased pH and calcium in the profile down to 4 feet deep 4 years after application. Cation exchange capacity increased slightly with 17 T/A in 4 years down to 3 1/2 feet in the profile.

Five tons coral stone (7 years after application) decreased exchangeable sodium and potassium in the profile of Akaka soil. Exchangeable calcium was depleted from the first foot depth and some from depths down to 3 feet.

In the high-lime experiment, the results suggest that heavy lime applications (17 T/A) 4 years earlier solubilized sulfate sulfur from the surface soil and that this sulfate moved down the profile as far as 3 feet.

Exchangeable magnesium and sodium in the profile were not affected much by heavy lime applications. Exchangeable potassium increased considerably in the first foot depth but not lower than this. This increase was probably due to better retention of potassium supplied by the continued application of potassic fertilizer.

Calcium silicate and lime increased the yield of Sudan but not of Para grass. The effect was probably due to calcium. There were significant correlations between yield of Sudan grass and calcium and silicon uptake. There was a significant correlation between extractable silicon and silicon uptake by Sudan grass. Para grass seemed to have a better feeding power than Sudan grass with respect to absorption of the major elements. Para grass also took up more sodium and sulfur than Sudan grass. These grasses took up almost the same amount of phosphate. Sudan grass absorbed more calcium than Para grass. There was some evidence (not statistically significant) that Para grass weathered non-exchangeable sodium and potassium from the cinders while this effect was scarcely evident when Sudan grass was the test plant.

TVA slag seemed to decrease sulfur uptake by grasses while lime had the opposite effect. A competitive effect between two anions may be responsible for the depression of sulfate uptake by silicate.

TVA slag did not significantly affect absorption of soil phosphorus by plants although there was a trend of increasing extractable phosphorus with increasing slag rates. Sudan grass, however, showed an increasing trend of phosphate uptake with increasing rates of slag applied.

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APPENDIX

TABLE 1. EFFECT OF SILICATE MATERIALS ON pH OF SURFACE SOIL, AKAKA SERIES. 1:1 SOIL-WATER RATIO, FIELD-MOIST SOIL. (SUMMARY IN TEXT TABLE V.)

	Rate	Replication			
Silicate carrier	(T/A)	1	2	3	4
TVA slag	0	5.4	5.3	5.4	5.4
	2	6.1	6.4	5.8	5.9
	4	6.1	6.1	6.5	6.3
	6	6.3	6.4	6.0	6.5
	8	7.0	6.6	6.6	6.6
Volcanic cinders	0	5.4	5.4	5.3	5.5
	1.22	5.3	5.4	5.5	5.5
	2.44	6.0	5.8	5.6	5.5
	3.66	5.6	5.3	5.5	5.2
	4.88	5.4	5.2	5.3	5.5
Volcanic cinders + coral stone	0	5.6	5.4	5.4	5.4
	2.65	5.8	5.9	5.6	6.0
	5.30	6.3	6.0	6.0	6.5
	7.95	6.3	6.2	6.4	6.8
	10.60	6.7	6.6	7.0	6.7

TABLE 2. EFFECT OF LIME AND PHOSPHATE ON pH OF SURFACE SOIL, AKAKA SERIES. 1:1 SOIL-WATER RATIO, FIELD-MOIST SOIL. (SUMMARY IN TEXT TABLE VI.)

P	Lime	Replication			
(lb/A)	(T/A)	1	2	3	4
0	0	5.0	5.0	4.9	5.3
	2	5.6	5.6	5.5	5.5
	9.5	6.8	6.7	7.1	7.0
	17	7.3	7.2	7.2	7.4
88	0	5.7	5.3	5.5	5.0
	2	5.8	5.6	5.8	6.0
	9.5	6.8	7.0	7.1	7.2
	17	7.2	7.0	7.2	7.2
176	0	4.9	5.2	4.9	5.1
	2	5.5	5.8	5.4	5.3
	9.5	6.8	6.1	6.1	6.6
	17	7.4	7.5	7.2	7.1

TABLE 3. EFFECT OF LIME APPLIED IN 1956 ON THE pH OF SOIL PROFILE. AKAKA SERIES, IN 1963. 1:1 SOIL-WATER RATIO. FIELD-MOIST SOIL. (SUMMARY IN TEXT TABLE VII.)

Lime		Depth (inches)							
(T/A)	Repl.	0-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48
0	1	4.7	5.0	5.1	5.3	5.4	5.4	5.5	5.0
	2	4.7	4.8	5.0	5.3	5.5	5.4	5.5	5.4
	3	4.7	4.9	5.0	5.4	5.6	5.6	5.7	5.6
0.5	1	4.8	5.0	5.2	5.3	5.3	5.5	5.4	5.3
	2	4.7	4.8	4.9	4.9	4.8	4.9	5.0	4.9
	3	5.0	5.0	5.2	5.3	5.4	5.5	5.5	5.6
1.0	1	5.0	4.7	5.0	5.0	5.0	5.1	5.5	5.4
	2	4.5	4.6	4.8	5.2	5.4	5.6	5.7	5.6
	3	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.6
2.5	1	5.3	5.6	5.6	5.6	5.7	5.8	5.8	5.6
	2	4.6	4.6	4.9	5.6	5.6	5.8	5.8	5.7
	3	4.9	5.0	5.2	5.4	5.5	5.5	5.6	5.5
5.0	1	5.2	5.1	5.4	5.6	5.8	5.8	6.0	6.0
	2	5.4	5.4	5.3	5.5	5.7	5.8	5.7	5.7
	3	4.8	4.9	5.1	5.3	5.5	5.4	5.6	5.6

TABLE 4. EFFECT OF LIME APPLIED IN 1959 ON THE pH OF SOIL PROFILE, AKAKA SERIES, IN 1963. 1:1 SOIL-WATER RATIO. FIELD-MOIST SOIL. (SUMMARY IN TEXT TABLE VIII.)

Lime (T/A)	Repl.	Depth (inches) 0-6	6-12	12-18	18-24	24-30	30-36	36-42	42-48
0	1	4.6	5.1	5.7	5.8	5.9	5.9	5.9	5.9
	2	4.6	4.8	5.2	5.6	5.8	5.7	5.8	5.8
	3	4.8	5.2	5.4	5.5	5.7	5.7	5.8	5.7
	4	5.3	5.0	5.5	5.8	5.8	5.7	5.8	5.6
2	1	5.4	5.2	5.3	5.4	5.5	5.7	5.7	5.8
	2	5.4	5.1	5.6	5.9	5.9	5.9	5.8	5.8
	3	5.1	4.9	5.4	5.8	5.8	5.7	5.8	5.8
	4	5.4	5.3	5.7	6.0	5.9	5.8	5.8	5.7
9.5	1	6.1	5.9	5.7	5.8	5.9	5.9	6.0	6.0
	2	5.9	5.9	5.6	5.8	5.9	6.0	6.0	5.9
	3	6.2	6.2	6.0	5.9	5.9	5.9	5.9	5.9
	4	6.2	5.7	5.8	6.1	6.1	6.2	6.2	6.0
17	1	6.7	6.6	6.5	6.2	6.3	6.4	6.4	6.3
	2	6.4	5.9	6.1	6.1	6.2	6.3	6.2	6.3
	3	7.2	6.6	6.2	6.1	6.1	6.2	6.4	6.4
	4	6.8	6.0	6.3	5.9	6.1	6.2	6.2	6.2

TABLE 5. FERTILIZER PHOSPHORUS REMAINING IN SOLUTION, PARTS PER BILLION P, AFTER 48 HOURS EQUILIBRATION IN 20 PPM P SOLUTION OF AKAKA SOIL TREATED WITH VARIOUS RATES OF SILICATE CARRIERS. 1:12.5 SOIL-SOLUTION RATIO. (SUMMARY IN TEXT TABLE 9.)

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	1.6	1.5	1.6	1.7
	2	2.6	4.9	4.6	3.8
	4	4.1	3.3	3.4	4.8
	6	2.9	3.1	3.6	4.2
	8	5.7	4.2	6.8	5.9
Volcanic cinders	0	1.9	2.3	3.6	3.5
	1.22	2.4	1.8	3.6	1.3
	2.44	2.6	1.4	1.7	3.4
	3.66	1.1	3.7	2.6	1.3
	4.88	3.6	2.3	2.4	2.5
Volcanic cinders	0	2.1	2.6	2.1	1.7
+ coral stone	2.65	1.7	2.4	1.8	2.3
	5.30	4.0	1.4	1.8	1.3
	7.95	1.7	1.6	2.1	1.9
	10.60	4.8	2.1	3.0	3.8

TABLE 6. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXTRACTABLE PHOSPHORUS, PPM, IN AKAKA SERIES USING TRUOG MODIFICATION A, AYRES AND HAGIHARA, 1952. FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE X).

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	4.5	4.2	3.5	3.2
	2	4.6	4.2	3.4	5.0
	4	5.6	6.4	4.1	4.9
	6	7.9	8.8	8.0	6.5
	8	5.7	6.8	6.7	5.8
Volcanic cinders	0	4.3	5.6	6.6	6.2
	1.22	7.5	7.2	6.2	6.4
	2.44	7.0	4.8	5.9	5.2
	3.66	4.6	5.1	4.4	4.3
	4.88	6.2	6.6	5.5	5.9

TABLE 7. EFFECT OF LIME AND PHOSPHATE ON EXTRACTABLE PHOSPHORUS, PPM, IN AKAKA SOIL, USING TRUOG MODIFICATION A, AYRES AND HAGIHARA, 1952; FIELD-MOIST BASIS, 45 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XI.)

P	Rate	Replication			
(lb/A)	(T/A)	1	2	3	4
0	0	3.6	3.8	3.1	4.4
	2	4.1	3.2	4.2	3.4
	9.5	2.9	2.4	2.4	2.2
	17	2.4	2.0	2.9	2.4
88	0	3.5	2.6	3.0	2.3
	2	4.2	4.5	3.4	2.9
	9.5	4.2	4.8	3.3	4.0
	17	3.7	3.3	4.2	4.5
176	0	3.4	3.0	3.6	2.7
	2	4.2	3.7	4.8	4.0
	9.5	4.9	5.2	6.0	5.7
	17	6.7	7.0	5.7	5.4

TABLE 8. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE Ca, ME/100 G, IN AKAKA SOIL. FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE XII.)

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	0.42	0.48	0.40	0.44
	2	1.92	1.65	1.53	1.71
	4	3.44	3.63	2.56	3.09
	6	4.89	4.90	4.22	4.39
	8	5.66	5.97	6.13	5.33
Volcanic cinders	0	0.27	0.29	0.34	0.35
	1.22	0.36	0.37	0.35	0.35
	2.44	0.48	0.38	0.43	0.39
	3.66	0.52	0.50	0.47	0.46
	4.88	0.44	0.44	0.40	0.40

TABLE 9. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE Ca, ME/100 G, IN AKAKA SOIL. FIELD-MOIST BASIS, 45 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XIII.)

P (lb/A)	Lime (T/A)	Replication 1	2	3	4
0	0	0.53	0.49	0.49	0.53
	2	1.21	1.19	1.19	1.21
	9.5	18.65	15.51	15.95	16.17
	17	18.96	18.34	20.64	21.47
88	0	0.47	0.38	0.44	0.42
	2	0.97	0.90	0.97	0.97
	9.5	16.38	15.05	15.21	14.56
	17	15.88	16.18	17.80	18.29
176	0	0.30	0.26	0.29	0.23
	2	0.71	0.92	1.00	0.91
	9.5	14.40	16.14	16.06	16.75
	17	16.40	18.82	17.40	17.98

TABLE 10. EFFECT OF HEAVY LIME APPLICATION ON CEC AND EXCHANGEABLE BASES, (ME/100 G) IN THE PROFILE OF AKAKA SOIL. (REPLICATES WERE COMPOSITED: FIELD-MOIST BASIS, 45 ± 3% DRY MATTER: MOIST WEIGHTS AT LOWER DEPTHS WERE ADJUSTED TO 0-12 INCHES.)

Depth	Zero-lime					17-T/A lime				
(inches)	CEC	Ca	Mg	K	Na	CEC	Ca	Mg	K	Na
					Unbufferred N NH_4Cl (pH 5.1)					
0- 6	29.13	1.07	0.51	0.14	0.063	30.52	14.44	0.61	0.25	0.077
6-12	27.36	1.07	0.53	0.08	0.063	33.00	3.90	0.35	0.09	0.065
12-18	25.32	0.91	0.55	0.10	0.070	29.72	2.94	0.31	0.09	0.063
18-24	24.68	0.75	0.45	0.09	0.059	25.86	2.09	0.26	0.09	0.063
24-30	21.75	0.64	0.39	0.07	0.059	24.89	1.87	0.28	0.08	0.063
30-36	21.19	0.70	0.35	0.08	0.059	23.82	1.82	0.18	0.07	0.065
36-42	21.34	0.96	0.26	0.09	0.059	23.44	1.66	0.16	0.06	0.059
42-48	19.30	0.96	0.23	0.07	0.059	22.37	1.60	0.17	0.05	0.061
					N neutral NH_4Ac					
0- 6	28.49	0.48	0.48	0.12	0.041	32.11	15.31	0.39	0.16	0.064
6-12	30.41	0.91	0.44	0.05	0.054	35.12	3.96	0.34	0.09	0.052
12-18	29.88	0.59	0.46	0.07	0.054	33.40	2.46	0.26	0.10	0.052
18-24	27.00	0.48	0.47	0.07	0.048	32.22	1.55	0.25	0.07	0.046
24-30	27.98	0.32	0.43	0.06	0.062	30.01	1.55	0.23	0.07	0.046
30-36	24.80	0.32	0.33	0.04	0.054	26.88	1.50	0.24	0.07	0.062
36-42	21.92	0.27	0.23	0.05	0.043	22.59	1.34	0.20	0.04	0.062
42-48	21.28	0.32	0.20	0.06	0.043	22.71	1.23	0.17	0.04	0.062

TABLE 11. EFFECT OF LIME APPLIED IN 1956 ON EXCHANGEABLE BASES (ME/100 G) IN THE PROFILE OF AKAKA SOIL SAMPLED IN 1963. (REPLICATES WERE COMPOSITED; FIELD-MOIST BASIS, 45 $\pm$ 3% DRY MATTER; LOWER MOIST WEIGHTS WERE ADJUSTED TO 0-12 INCHES)

Lime (T/A)	Depth (in.)	Ca	Mg	K	Na
0	0- 6	0.34	0.10	0.084	0.052
	6-12	0.38	0.12	0.080	0.042
	12-24	0.18	0.10	0.058	0.039
	24-36	0.19	0.08	0.050	0.039
	36-48	0.16	0.08	0.046	0.036
0.5	0- 6	0.35	0.11	0.053	0.042
	6-12	0.45	0.13	0.056	0.042
	12-24	0.32	0.13	0.031	0.042
	24-36	0.26	0.07	0.035	0.039
	36-48	0.16	0.06	0.042	0.036
1.0	0- 6	0.34	0.14	0.062	0.045
	6-12	0.47	0.13	0.058	0.045
	12-24	0.30	0.12	0.035	0.039
	24-36	0.22	0.09	0.031	0.036
	36-48	0.19	0.06	0.038	0.033
2.5	0- 6	0.37	0.13	0.073	0.036
	6-12	0.48	0.15	0.073	0.039
	12-24	0.32	0.14	0.042	0.036
	24-36	0.22	0.10	0.025	0.033
	36-48	0.18	0.06	0.042	0.033
5.0	0- 6	0.37	0.19	0.077	0.039
	6-12	0.42	0.20	0.060	0.039
	12-24	0.39	0.06	0.054	0.036
	24-36	0.27	0.07	0.038	0.036
	36-48	0.18	0.06	0.038	0.036

TABLE 12. EFFECT OF TVA SLAG ON EXTRACTABLE ALUMINUM IN AKAKA SOIL. (REPLICATES WERE COMPOSITED, FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. EXTRACTANT: N $BaCl_2$ pH 4.0; 2 HR. SHAKING)

Slag rate (T/A)	Extractable Al (me/100 g)
0	3.11
2	1.56
4	0.89
6	0.67
8	0.44

TABLE 13. EFFECTS OF LIME AND PHOSPHATE ON EXTRACTABLE ALUMINUM (ME/100 G) IN THE SURFACE SOIL OF AKAKA SERIES. (REPLICATES WERE COMPOSITED; FIELD-MOIST BASIS, 45 $\pm$ 3% DRY MATTER. EXTRACTANT: N $BaCl_2$ pH 4.0, 2 HR. SHAKING)

P	Lime (T/A)			
(lb/A)	0	2	9.5	17
0	3.33	1.33	0.56	0.22
88	2.78	0.95	0.78	0.44
176	3.22	1.11	0.89	0.67

TABLE 14. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE Mg, ME/100 G, IN AKAKA SOIL. FIELD-MOIST BASIS, 40 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XIV.)

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	0.08	0.07	0.08	0.12
	2	0.18	0.17	0.15	0.21
	4	0.58	0.52	0.48	0.65
	6	0.91	0.99	0.86	0.91
	8	1.03	1.08	1.02	1.13
Volcanic cinders	0	0.06	0.08	0.09	0.09
	1.22	0.13	0.12	0.13	0.10
	2.44	0.11	0.13	0.15	0.14
	3.66	0.11	0.14	0.13	0.13
	4.88	0.14	0.12	0.13	0.11

TABLE 15. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE Mg, ME/100 G, IN AKAKA SOIL. FIELD-MOIST BASIS, 45 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XV.)

P (lb/A)	Lime (T/A)	Replication 1	Replication 2	Replication 3	Replication 4
0	0	0.09	0.08	0.07	0.08
	2	0.13	0.11	0.13	0.13
	9.5	1.03	0.95	0.93	0.99
	17	1.03	1.26	1.05	1.33
88	0	0.17	0.17	0.19	0.18
	2	0.22	0.19	0.24	0.24
	9.5	1.24	1.16	1.12	1.17
	17	1.40	1.07	1.38	1.28
176	0	0.28	0.30	0.29	0.24
	2	0.56	0.43	0.47	0.63
	9.5	1.42	1.31	1.38	1.02
	17	1.75	1.49	1.57	1.07

TABLE 16. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE K (ME/100 G) IN AKAKA SOIL. FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE XVI.)

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	0.061	0.050	0.057	0.062
	2	0.082	0.092	0.082	0.088
	4	0.138	0.124	0.121	0.098
	6	0.115	0.119	0.107	0.105
	8	0.134	0.130	0.144	0.140
Volcanic cinders	0	0.044	0.058	0.065	0.062
	1.22	0.068	0.066	0.059	0.055
	2.44	0.073	0.055	0.061	0.057
	3.66	0.066	0.071	0.062	0.062
	4.88	0.070	0.070	0.063	0.072

TABLE 17. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE K (ME/100 G) IN AKAKA SOIL. FIELD MOIST-BASIS, 45 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XVII.)

P	Lime	Replication			
(lb/A)	(T/A)	1	2	3	4
0	0	0.084	0.068	0.071	0.079
	2	0.074	0.079	0.082	0.090
	9.5	0.154	0.130	0.133	0.138
	17	0.132	0.120	0.125	0.150
88	0	0.087	0.073	0.091	0.076
	2	0.098	0.098	0.095	0.102
	9.5	0.142	0.130	0.147	0.117
	17	0.111	0.127	0.129	0.127
176	0	0.084	0.078	0.085	0.075
	2	0.070	0.078	0.094	0.099
	9.5	0.114	0.130	0.135	0.136
	17	0.152	0.153	0.151	0.151

TABLE 18. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON EXCHANGEABLE Na (ME/100 G) IN AKAKA SOIL. FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE XVIII.)

Silicate carrier	Rate (T/A)	Replication 1	2	3	4
TVA slag	0	0.020	0.020	0.021	0.020
	2	0.032	0.036	0.034	0.035
	4	0.046	0.046	0.044	0.045
	6	0.064	0.059	0.050	0.041
	8	0.057	0.059	0.061	0.052
Volcanic cinders	0	0.018	0.021	0.023	0.023
	1.22	0.022	0.021	0.019	0.020
	2.44	0.030	0.027	0.026	0.024
	3.66	0.031	0.027	0.027	0.023
	4.88	0.030	0.024	0.022	0.024

TABLE 19. EFFECT OF LIME AND PHOSPHATE ON EXCHANGEABLE Na (ME/100 G) IN AKAKA SOIL. FIELD-MOIST BASIS, 45 ± 3% DRY MATTER. (SUMMARY IN TEXT TABLE XIX.)

P (lb/A)	Lime (T/A)	Replication 1	2	3	4
0	0	0.027	0.027	0.025	0.028
	2	0.036	0.036	0.033	0.033
	9.5	0.047	0.048	0.048	0.045
	17	0.047	0.048	0.046	0.047
88	0	0.025	0.022	0.028	0.022
	2	0.028	0.024	0.027	0.027
	9.5	0.055	0.048	0.045	0.039
	17	0.047	0.045	0.047	0.047
176	0	0.020	0.020	0.026	0.020
	2	0.025	0.028	0.035	0.032
	9.5	0.037	0.039	0.039	0.040
	17	0.046	0.044	0.040	0.045

TABLE 20. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON EXTRACTABLE Si (PPM) IN AKAKA SOIL. FIELD-MOIST BASIS, 40 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE XXI.)

Rate (T/A)	Replication 1	2	3	4
0	96	99	93	95
2	191	193	187	183
4	233	231	241	243
6	254	259	250	252
8	350	330	345	331

TABLE 21. EFFECT OF VARIOUS AMOUNTS OF LIME ON EXTRACTABLE Si (PPM) IN AKAKA SOIL. FIELD-MOIST BASIS, 45 $\pm$ 3% DRY MATTER. (SUMMARY IN TEXT TABLE XXII.)

Rate	Replication			
(T/A)	1	2	3	4
0	100	105	97	101
2	107	107	110	112
9.5	115	114	112	115
17	127	125	121	125

TABLE 22. EFFECT OF LIME AND PHOSPHATE ON EXTRACTABLE S (PPM) IN AKAKA SOIL. (REPLICATES WERE COMPOSITED; FIELD-MOIST BASIS, 45 ± 3% DRY MATTER.)

P (lb/A)	Lime (T/A)	Water-soluble S	KH_2PO_4-extractable S
0	0	1.6	245
	2	4.1	216
	9.5	14.6	173
	17	27.6	168
88	0	1.6	295
	2	4.1	276
	9.5	22.8	194
	17	29.3	168
176	0	1.6	310
	2	5.7	266
	9.5	13.8	233
	17	24.4	132

TABLE 23. EFFECT OF HEAVY LIME APPLICATION ON EXTRACTABLE S (PPM) IN THE PROFILE OF AKAKA SOIL. (REPLICATES WER E COMPOSITED; FIELD-MOIST BASIS, 45 $\pm$ 3% DRY MATTER; MOIST WEIGHTS OF LOWER DEPTHS WERE ADJUSTED TO 0-12 INCHES.)

Depth (in.)	Zero-lime	17-T/A lime
0- 6	237	156
6-12	218	240
12-18	232	240
18-24	215	264
24-30	224	263
30-36	225	269
36-42	245	255
42-48	240	238

TABLE 24. EFFECTS OF SILICATE AND CARBONATE ON THE YIELD OF SUGAR CANE (AFTER CLEMENTS, IN PRESS). VALUES ARE MEANS OF 4 REPLICATES.

Treatment	TCA	TPA	Pol % cane
TVA slag (A)	85.4	10.28	12.10
Volcanic cinders (B)	74.9	9.27	12.44
TVA slag coral stone (C)	80.3	9.44	11.85
	A* over C and ** over B. C* over B.	C and B are equal. A** over both.	n.s.

TABLE 25. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON YIELD (G/POT DRY MATTER) OF SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXIV.)

Silicate carrier	Rate (T/A)	Replication 1	2	3
	Sudan grass			
TVA slag	0	11.28	9.26	11.40
	2	13.55	14.42	13.34
	4	14.60	15.22	13.88
	6	15.26	15.50	16.05
	8	13.62	13.82	14.67
Volcanic cinders	0	9.05	7.96	9.48
	1.22	9.00	11.96	10.31
	2.44	10.37	9.05	11.00
	3.66	9.19	10.48	6.90
	4.88	9.27	8.82	9.40
	Para grass			
TVA slag	0	14.15	15.00	14.00
	2	15.83	14.49	13.02
	4	13.40	14.66	14.40
	6	15.38	15.15	14.52
	8	14.73	15.38	14.05
Volcanic cinders	0	15.88	13.96	15.01
	1.22	11.44	12.74	13.29
	2.44	15.12	13.62	14.94
	3.66	15.10	11.73	15.29
	4.88	13.64	13.86	13.16

TABLE 26. EFFECT OF LIME AND PHOSPHATE ON YIELD (G/POT DRY MATTER) OF SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXV.)

P	Lime	SUDAN GRASS Replication			PARA GRASS Replication		
(lb/A)	(T/A)	1	2	3	1	2	3
0	0	10.19	8.40	7.43	12.23	14.60	12.79
	2	10.35	9.14	11.60	16.45	14.05	14.79
	9.5	12.93	11.95	12.79	12.71	14.00	14.50
	17	13.00	13.86	13.68	14.20	14.25	14.30
88	0	8.80	10.45	9.50	13.59	14.35	15.80
	2	9.96	7.75	11.84	13.97	13.50	13.58
	9.5	12.73	14.01	12.56	13.95	13.16	13.00
	17	11.66	12.39	13.44	11.35	13.24	11.35
176	0	7.30	6.76	9.02	14.15	13.14	15.23
	2	12.41	9.15	12.10	12.47	15.74	14.83
	9.5	12.00	12.15	11.73	12.61	14.10	14.59
	17	11.86	12.80	11.27	11.48	12.80	13.01

TABLE 27. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON PHOSPHORUS UPTAKE, (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXVI.)

Silicate carrier	Rate (T/A)	SUDAN GRASS Replication 1	SUDAN GRASS Replication 2	SUDAN GRASS Replication 3	PARA GRASS Replication 1	PARA GRASS Replication 2	PARA GRASS Replication 3
TVA slag	0	10.83	7.41	9.12	11.74	11.70	11.48
	2	9.21	8.65	8.00	14.25	12.03	14.19
	4	7.59	8.52	10.13	10.18	13.19	10.66
	6	11.14	9.61	8.35	12.76	12.88	13.79
	8	9.94	9.40	9.10	13.70	14.76	13.49
Volcanic cinders	0	8.87	9.39	11.85	11.59	12.98	11.11
	1.22	7.92	10.28	9.79	12.47	11.85	12.23
	2.44	9.64	10.32	10.45	12.10	11.98	11.65
	3.66	10.48	11.42	8.00	13.59	10.32	14.07
	4.88	10.38	9.70	9.40	12.28	13.86	12.50

TABLE 28. EFFECT OF LIME AND PHOSPHATE ON TOTAL PHOSPHORUS UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXVII.)

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	SUDAN GRASS Replication 2	SUDAN GRASS Replication 3	PARA GRASS Replication 1	PARA GRASS Replication 2	PARA GRASS Replication 3
0	0	9.17	8.40	8.62	8.56	10.80	10.23
	2	9.62	10.60	11.02	11.52	11.24	10.80
	9.5	10.60	11.95	11.00	9.66	12.38	11.89
	17	14.30	14.83	14.64	11.79	12.26	13.30
88	0	9.68	9.61	10.64	10.60	12.34	13.11
	2	8.56	7.21	8.76	10.90	9.86	9.91
	9.5	9.42	10.93	10.42	10.60	9.61	12.48
	17	10.84	13.50	11.42	8.85	10.59	10.22
176	0	7.15	7.84	8.39	12.17	11.17	10.05
	2	11.17	8.51	10.41	12.22	13.06	11.27
	9.5	9.48	11.66	10.91	10.84	11.56	13.13
	17	10.20	9.98	10.14	9.41	9.47	9.89

TABLE 29. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON SOIL PHOSPHORUS UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXVIII.)

Silicate carrier	Rate (T/A)	SUDAN GRASS Replication 1	SUDAN GRASS Replication 2	SUDAN GRASS Replication 3	PARA GRASS Replication 1	PARA GRASS Replication 2	PARA GRASS Replication 3
TVA slag	0	1.58	1.11	2.05	3.25	3.60	1.54
	2	2.30	3.75	3.46	4.75	4.64	4.95
	4	2.04	3.65	2.50	2.81	4.69	4.90
	6	1.07	2.01	1.13	2.15	3.94	2.47
	8	3.13	3.32	3.53	4.27	7.53	4.92
Volcanic cinders	0	2.81	3.34	3.79	5.56	4.46	4.96
	1.22	2.16	3.22	2.26	3.78	6.25	5.19
	2.44	3.21	3.71	2.09	2.73	2.45	3.73
	3.66	3.96	3.66	1.65	3.17	3.40	5.97
	4.88	3.80	3.70	3.01	3.82	4.85	4.34

TABLE 30. EFFECT OF LIME AND PHOSPHATE ON SOIL PHOSPHORUS UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXIX).

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
0	0	2.45	1.26	2.08	1.47	3.79	2.43
	2	2.17	3.11	1.22	3.62	3.37	4.14
	9.5	3.36	3.27	1.79	2.80	4.54	4.49
	17	4.16	2.63	2.60	2.99	3.42	3.72
88	0	1.67	2.29	3.04	3.26	3.44	2.84
	2	2.58	1.17	3.31	4.06	1.49	2.58
	9.5	3.06	3.93	3.89	4.04	2.77	4.68
	17	1.28	3.59	2.55	2.27	5.16	2.73
176	0	2.11	2.23	2.44	2.41	2.76	2.89
	2	1.86	0.92	2.42	3.24	3.46	2.67
	9.5	2.52	3.52	4.11	2.77	4.51	4.52
	17	2.85	3.58	4.50	2.98	2.30	2.99

TABLE 31. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON FERTILIZER PHOSPHORUS UPTAKE (MG/POT P^{32}) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXX)

Silicate carrier	Rate (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
TVA slag	0	9.25	6.30	7.07	8.49	8.10	9.94
	2	6.91	4.90	4.54	9.50	7.39	9.24
	4	5.55	4.87	7.63	7.37	8.50	5.76
	6	10.07	7.60	7.22	10.61	8.94	11.32
	8	6.81	6.08	5.57	9.43	7.23	8.57
Volcanic cinders	0	6.06	6.05	8.06	6.03	8.52	6.15
	1.22	5.76	7.06	7.53	8.69	5.60	7.04
	2.44	6.43	6.61	8.36	9.37	9.53	7.92
	3.66	6.52	7.76	6.35	10.42	6.92	8.10
	4.88	6.58	6.00	6.39	8.46	9.01	8.16

TABLE 32. EFFECT OF LIME AND PHOSPHATE ON FERTILIZER PHOSPHORUS UPTAKE (MG/POT P^{32}) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXI.)

P	Lime	SUDAN GRASS Replication			PARA GRASS Replication		
(lb/A)	(T/A)	1	2	3	1	2	3
0	0	6.72	7.14	6.54	7.09	7.01	7.80
	2	7.45	7.49	9.86	7.90	7.87	6.66
	9.5	7.24	8.60	9.21	6.86	7.84	7.40
	17	10.14	12.20	12.04	8.80	8.84	9.58
88	0	8.01	7.32	7.60	7.34	8.90	10.27
	2	5.98	6.04	5.45	6.84	8.37	7.35
	9.5	6.36	7.00	6.53	6.56	6.84	7.80
	17	9.56	9.91	8.87	6.58	5.43	7.49
176	0	5.04	5.61	5.95	9.76	8.41	7.16
	2	9.31	7.59	7.99	8.98	9.60	8.60
	9.5	6.96	8.14	6.80	8.07	7.05	8.61
	17	7.35	6.40	5.64	6.43	7.17	6.90

TABLE 33. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON PHOSPHORUS A-VALUE (PPM) AS DETERMINED BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXII.)

		SUDAN GRASS Replication			PARA GRASS Replication		
Silicate carrier	Rate (T/A)	1	2	3	1	2	3
TVA slag	0	17.1	17.6	29.0	38.3	44.4	15.5
	2	33.3	45.3	76.2	50.0	62.8	53.6
	4	36.8	75.0	32.8	38.1	55.2	85.1
	6	10.6	26.4	15.6	20.3	44.1	21.8
	8	46.0	54.6	63.4	45.3	104.2	57.4
Volcanic cinders	0	46.4	55.2	47.0	92.2	52.3	80.6
	1.22	37.5	45.6	30.0	43.5	111.6	73.7
	2.44	49.9	56.1	25.0	29.1	25.7	47.1
	3.66	60.8	47.2	26.0	30.4	39.1	73.7
	4.88	57.8	61.7	47.1	45.2	53.8	53.2

TABLE 34. EFFECT OF LIME AND PHOSPHATE ON PHOSPHORUS A-VALUE (PPM) AS DETERMINED BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXIII.)

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
0	0	36.5	17.6	31.8	20.7	54.1	31.2
	2	29.1	41.5	11.8	45.8	42.8	62.2
	9.5	46.4	39.0	19.4	40.8	57.9	60.7
	17	41.0	21.6	21.6	34.0	38.7	38.8
88	0	20.8	31.3	40.0	44.4	38.7	27.6
	2	43.1	19.4	60.8	59.4	17.8	35.2
	9.5	48.1	56.2	59.6	61.6	40.5	60.0
	17	13.4	36.2	28.8	34.5	95.0	36.4
176	0	41.9	39.7	41.0	24.7	32.8	40.4
	2	20.0	12.1	30.3	36.1	36.0	31.0
	9.5	36.2	43.2	60.4	34.3	64.0	52.5
	17	38.8	55.9	79.8	46.4	32.1	43.3

TABLE 35. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON Ca UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXIV.)

		SUDAN GRASS Replication			PARA GRASS Replication		
Silicate carrier	Rate (T/A)	1	2	3	1	2	3
TVA slag	0	27.86	24.08	27.13	22.07	24.00	23.10
	2	52.84	48.74	44.56	30.87	30.14	27.08
	4	51.25	61.34	51.77	29.08	29.32	29.23
	6	60.12	63.08	59.06	30.76	32.88	29.04
	8	60.88	58.04	59.12	34.47	30.76	31.09
Volcanic cinders	0	24.34	21.01	28.82	31.76	27.22	27.32
	1.22	21.87	28.46	25.46	18.30	23.19	24.19
	2.44	28.83	27.06	30.03	23.59	23.02	25.85
	3.66	24.26	30.39	20.63	27.48	21.82	26.60
	4.88	26.14	24.87	28.11	23.73	23.42	26.85

TABLE 36. EFFECT OF LIME AND PHOSPHATE ON Ca UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXV.)

P	Lime	SUDAN GRASS Replication			PARA GRASS Replication		
(lb/A)	(T/A)	1	2	3	1	2	3
0	0	20.28	20.41	17.45	13.82	17.81	17.14
	2	30.02	26.58	33.18	26.32	24.45	28.25
	9.5	60.51	59.03	63.18	36.35	36.40	39.59
	17	68.77	60.15	62.93	38.77	40.76	42.18
88	0	29.04	28.11	23.94	22.42	18.66	23.38
	2	26.29	23.56	29.24	21.23	24.57	22.41
	9.5	48.63	53.52	54.51	31.33	33.69	30.94
	17	55.15	66.66	57.79	24.06	25.28	27.58
176	0	17.08	19.33	21.92	25.75	27.33	30.46
	2	37.73	30.56	33.64	26.44	28.65	29.66
	9.5	46.80	46.90	43.17	29.51	36.66	32.97
	17	67.84	70.91	61.53	35.82	32.26	35.00

TABLE 37. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON ALUMINUM UPTAKE (ME/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL.

Silicate carrier	Rate (T/A)	SUDAN GRASS Replication 1	SUDAN GRASS Replication 2	SUDAN GRASS Replication 3	PARA GRASS Replication 1	PARA GRASS Replication 2	PARA GRASS Replication 3
TVA slag	0	1.13	2.41	3.54	3.68	3.55	3.36
	2	1.63	1.44	1.87	3.96	3.48	2.34
	4	1.75	1.82	2.50	1.61	1.76	1.73
	6	1.68	1.55	1.77	1.69	1.82	2.04
	8	2.18	1.52	2.20	2.06	2.00	2.25
Volcanic cinders	0	2.26	1.99	1.80	4.45	2.65	2.25
	1.22	1.62	1.44	1.65	2.06	2.29	1.73
	2.44	1.86	1.63	1.87	1.97	2.18	2.54
	3.66	1.65	1.57	1.59	3.32	2.70	2.44
	4.88	1.80	1.41	1.69	2.59	2.36	2.53

TABLE 38. EFFECT OF LIME AND PHOSPHATE ON ALUMINUM UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL.

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
0	0	1.22	1.09	1.11	1.59	2.34	2.18
	2	1.35	1.10	1.28	2.14	2.81	2.52
	9.5	1.81	1.79	2.05	1.65	2.52	2.76
	17	1.69	1.94	1.91	2.56	2.14	2.14
88	0	1.50	1.57	1.52	1.90	2.40	2.53
	2	1.29	1.16	1.42	1.96	1.89	2.31
	9.5	1.66	1.96	1.76	2.37	2.50	2.21
	17	1.63	2.10	2.42	1.70	2.65	1.70
176	0	1.17	1.46	1.53	1.98	2.50	2.28
	2	1.36	1.83	1.57	2.62	1.89	2.52
	9.5	1.44	1.46	1.07	2.27	2.54	2.19
	17	1.42	1.54	1.46	1.61	1.66	1.82

TABLE 39. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON Mg UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXVI.)

		SUDAN GRASS Replication			PARA GRASS Replication		
Silicate carrier	Rate (T/A)	1	2	3	1	2	3
TVA slag	0	29.67	27.78	34.77	41.18	37.50	36.40
	2	30.62	27.69	26.28	35.93	31.01	31.12
	4	26.86	25.87	26.93	26.00	29.17	32.98
	6	29.15	26.82	27.44	27.07	30.00	28.89
	8	23.29	24.46	25.67	28.87	25.85	28.94
Volcanic cinders	0	26.88	24.28	28.25	39.86	37.27	36.77
	1.22	26.37	34.44	29.90	33.75	36.56	35.22
	2.44	30.28	25.88	31.02	36.29	34.87	35.11
	3.66	26.19	30.29	23.04	38.50	32.84	37.46
	4.88	29.11	26.64	29.70	37.78	37.70	39.35

TABLE 40. EFFECT OF LIME AND PHOSPHATE ON Mg UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXVII.)

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
0	0	32.00	28.81	25.34	29.11	36.35	33.76
	2	33.53	31.99	35.84	35.37	31.61	33.57
	9.5	25.60	26.89	26.22	21.22	21.28	24.22
	17	21.97	25.22	26.54	24.00	26.22	26.31
88	0	29.92	34.17	28.22	39.41	38.60	35.71
	2	24.60	21.54	37.41	27.38	26.32	32.59
	9.5	35.13	33.34	28.51	27.34	22.37	28.60
	17	26.00	25.52	36.56	23.15	28.73	24.97
176	0	22.12	22.10	24.80	33.25	35.61	43.25
	2	34.25	27.27	32.91	32.55	34.94	33.96
	9.5	23.76	29.28	26.86	26.86	32.71	29.32
	17	26.09	27.65	28.51	21.35	21.38	24.72

TABLE 41. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON K UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXVIII.)

Silicate carrier	Rate (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
TVA slag	0	194	193	208	202	204	226
	2	227	221	230	244	203	233
	4	225	230	221	218	246	248
	6	243	244	219	237	264	243
	8	231	244	232	262	218	243
Volcanic cinders	0	193	178	199	212	198	204
	1.22	196	211	203	209	241	236
	2.44	209	208	209	241	229	237
	3.66	193	181	164	241	214	234
	4.88	202	198	192	222	242	244

TABLE 42. EFFECT OF LIME AND PHOSPHATE ON K UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XXXIX.)

P (lb/A)	Lime (T/A)	SUDAN GRASS Replication 1	2	3	PARA GRASS Replication 1	2	3
0	0	222	194	207	205	247	266
	2	230	207	243	291	286	288
	9.5	220	254	237	241	285	292
	17	262	232	260	279	285	304
88	0	207	227	228	249	265	288
	2	226	208	247	291	245	289
	9.5	274	274	273	291	244	292
	17	217	246	250	237	257	257
176	0	229	197	197	250	250	255
	2	236	211	202	258	264	271
	9.5	253	253	251	268	275	278
	17	252	259	250	246	191	177

TABLE 43. EFFECT OF TVA SLAG AND VOLCANIC CINDERS ON Na UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XL.)

		SUDAN GRASS Replication			PARA GRASS Replication		
Silicate carrier	Rate (T/A)	1	2	3	1	2	3
TVA slag	0	2.16	2.82	3.11	9.21	10.40	10.46
	2	3.86	3.60	2.61	15.84	10.55	11.73
	4	2.80	4.87	3.75	16.43	18.93	13.30
	6	4.88	4.25	3.08	21.50	21.18	24.33
	8	5.24	3.73	3.90	22.17	19.64	24.22
Volcanic cinders	0	2.79	1.84	1.97	12.23	11.56	8.68
	1.22	2.47	1.98	1.78	8.81	10.79	10.23
	2.44	2.48	1.56	3.14	11.52	13.21	10.88
	3.66	2.83	1.61	1.67	15.05	11.42	11.90
	4.88	2.53	2.31	1.92	13.65	11.74	13.07

TABLE 44. EFFECT OF LIME AND PHOSPHATE ON Na UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XLI.)

P	Lime	SUDAN GRASS Replication			PARA GRASS Replication		
(lb/A)	(T/A)	1	2	3	1	2	3
0	0	2.35	1.55	2.01	9.42	11.75	12.30
	2	1.64	2.11	1.60	14.57	17.67	13.78
	9.5	1.50	1.84	1.87	11.98	17.22	17.70
	17	2.50	2.13	2.64	18.06	17.92	14.31
88	0	2.38	2.01	2.56	11.77	12.31	13.87
	2	3.11	2.12	5.67	13.61	11.43	16.65
	9.5	3.18	6.91	4.11	12.62	10.74	13.01
	17	1.89	2.53	1.81	9.61	16.17	14.23
176	0	1.97	1.04	2.36	11.34	12.14	9.85
	2	1.91	2.29	1.86	12.48	13.27	12.44
	9.5	4.20	3.89	2.71	10.44	13.56	13.03
	17	2.74	2.46	2.16	10.83	9.37	10.02

TABLE 45. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON Si UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL IN POTS. (SUMMARY IN TEXT TABLE XLII.)

Rate	SUDAN GRASS Replication			PARA GRASS Replication		
(T/A)	1	2	3	1	2	3
0	38	32	34	32	35	38
2	85	91	75	107	109	115
4	129	134	115	107	128	138
6	150	147	157	147	147	132
8	156	152	147	142	151	151

TABLE 46. EFFECT OF VARYING AMOUNTS OF LIME ON Si UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XLIII.)

Rate	SUDAN GRASS Replication			PARA GRASS Replication		
(T/A)	1	2	3	1	2	3
0	37	36	33	31	34	36
2	39	37	34	37	35	39
9.5	36	34	34	34	35	36
17	41	38	35	35	34	37

TABLE 47. EFFECT OF VARYING AMOUNTS OF TVA SLAG ON S UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XLIV.)

Rate	SUDAN GRASS Replication			PARA GRASS Replication		
(T/A)	1	2	3	1	2	3
0	8.00	6.58	7.98	30.39	33.69	34.54
2	9.14	8.22	9.22	35.76	31.49	30.52
4	6.39	7.73	6.19	23.69	25.73	23.33
6	7.08	6.23	7.03	28.13	26.22	24.77
8	6.67	5.80	6.92	24.95	24.58	23.97

TABLE 48. EFFECTS OF SILICATE AND CARBONATE ON THE SULFUR UPTAKE OF SUGAR CANE. VALUES ARE % OF DRY MATTER OF SHEATH AND ARE MEANS OF 4 REPLICATES. (AFTER CLEMENTS, 1965, IN PRESS.)

	Rate (T/A)					
Treatment	0	2	4	6	8	Ave.
TVA slag (A)	0.176	0.139	0.177	0.156	0.135	0.157
Volcanic cinders (B)	0.176	0.166	0.135	0.192	0.179	0.170
Volcanic cinders + coral stone (C)	0.176	0.222	0.215	0.178	0.195	0.197

C - coral stone and cinders, quadratic regression is ** significant, ($F = 17.73^{**}$)

TABLE 49. EFFECT OF VARYING AMOUNTS OF LIME ON S UPTAKE (MG/POT) BY SUDAN AND PARA GRASSES GROWN ON AKAKA SOIL. (SUMMARY IN TEXT TABLE XLV.)

Rate	SUDAN GRASS Replication			PARA GRASS Replication		
(T/A)	1	2	3	1	2	3
0	8.11	6.39	7.02	29.88	32.44	31.08
2	7.34	7.60	8.72	29.08	26.74	30.67
9.5	8.38	8.78	7.16	32.60	30.76	32.57
17	11.49	9.83	9.93	32.08	30.12	28.26